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MERL Report of Progress, 1978

(U.S.) Municipal Environmental Research Lab, Cincinnati, OH

Apr 79

United States
Environmental Protection
Agency

Municipal Environmental Research
Laboratory
Cincinnati OH 45268

EPA-600/9-79-009
April 1979

PB 295508

Research and Development

Report
of
Progress

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ENVIRONMENTAL ROOTS

When the Environmental Protection Agency was created in December 1970, it marked an awakening of an environmental conscience in America. For the first time there was a governmental structure designed to approach pollution control problems in terms of the total interrelated environment. Research was an important part of the new Agency, and four National Environmental Research Centers were established to conduct studies on the health and ecological effects of environmental contaminants, and to pursue technological solutions of pollution problems. Since that time, the structure of th EPA's research arm has evolved to fifteen research laboratories located throughout the United States.

The MERL is one of those fifteen laboratories, and one of four in the Office of Air, Land and Water Use. The others are the Environmental Sciences Research Laboratory (ESRL) at the Research Triangle Park, North Carolina; the Environmental Research Laboratory (ERL) at Athens, Georgia; and the Robert S. Kerr Environmental Research Laboratory at Ada, Oklahoma.

The history and tradition of Federal evironmental rcsearch in Cincinnati is impressive, and is more than 60 years old. In 1913 the U.S. Public Health Service established a "stream station" in Cincinnati to conduct research in public water supply and water pollution control. The commercial and industrial pulse of the nation quickened and became powerful over the decades, but there was not a comparable growth in pollution prevention. Nevertheless, research continued in Cincinnati, and by the middle 50's, the newly-constructed Robert A. Taft Sanitary Engineering Center became internationally known for pollution control research. As environmental research efforts grew, the Sanitary Engineering Center became too small. In July 1975, President Ford dedicated the Environmental Research Center located next to the University of Cincinnati, and in January 1976, the MERL and other EPA organizations occupied the twenty-eight million dollar facility.

The building blocks of technological advance in pollution control have been constructed on the firm foundation of scientific research performed by our predecessors in Cincinnati. We are proud to carry on an impressive tradition, and will do our best to preserve and enhance our natural heritage.

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16. ABSTRACT

The Municipal Enviornmental Research Laboratory is EPA's research component for the development of technology, systems and processes to combat environmental pollutants that trouble our communities and municipalities. The MERL Report of Progress will provide you with updated information about the programs of the Laboratory.

The report will discuss the development and demonstration of cost-effective pollution control methods in the areas of sewage and wastewaters, solid and hazardous wastes, public drinking water supplies, and urban systems management.

Although some of its content is technical, the report is written to be informative for a wide management audience in the business and industry, education, and government, and others who are interested in the environment and related fields.

Discusses

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Pollution	Water Supply	Solid Waste Research	
Abatement	Sewage Treatment	Hazardous Waste Research	13B
Water Reclamation	Water Treatment	Drinking Water Research	
Wastes	Waste Disposal	Wastewater Research	

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EPA

Report of Progress

MERL '78

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DISCLAIMER

This report has been reviewed by the Municipal Environmental Research Laboratory and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

FOREWORD

The chief aim and primary purpose of our laboratory is to develop technology, systems, processes and improved management practices to prevent, control and treat pollutants that affect communities and municipalities. We develop and demonstrate cost-effective methods in the areas of sewage and wastewaters, solid and hazardous wastes, and public drinking water supplies.

We recognize our responsibility to help establish and maintain communications with our user community. We are also aware that every effort must be made to reduce the time it takes to move research findings from the laboratory to the user. This publication is one way for us to share with you our research results. It briefly outlines our progress during 1978. Should you have any comments about this publication, or suggestions for its improvement, please take the time to write to me.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

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OFFICE OF THE DIRECTOR

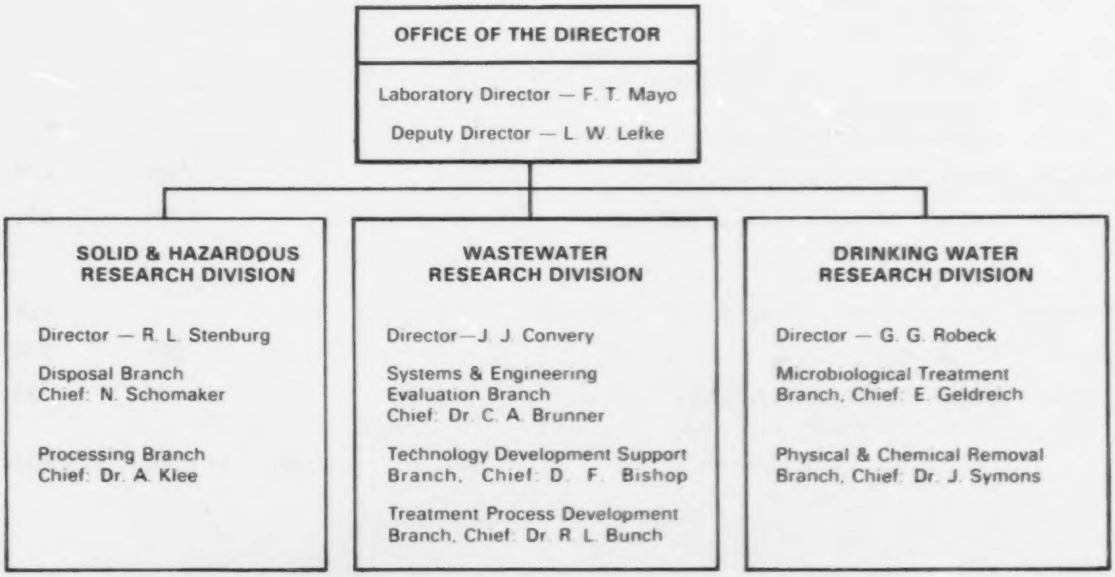
The MERL's Office of the Director provides management direction and administrative support to the three line divisions of the Laboratory. In fiscal year 1978 special emphasis was placed in two areas. One was a more complete integration of the planning process, and the other concerned program analysis.

INTEGRATING THE PLANNING PROCESS

While zero base budgeting (ZBB) has become the key Agency procedure for program planning, laboratory participation comes at a later stage in the planning process. In 1978, the MERL Director and senior staff made a concerted effort to become involved in the preparation of fiscal year 1979 (FY 79) objective statements by the Office of Air, Land and Water Use (OALWU), and to guarantee that laboratory accomplishment plans were reconciled precisely with Headquarters objectives. Joint OALWU/MERL planning sessions contributed to mutual agreement and understandings that were reflected in laboratory task work plans. That kind of cooperative effort will be extended to the FY 80 laboratory planning process. Likewise the program review format has been changed from a task-by-task status report to a joint OALWU/MERL discussion of program issues with participation from the EPA Program Offices, especially in the area of identifying Program Office needs. That format and a desire on the part of MERL to modify program plans to meet Agency research needs have positively influenced the research effort to be more responsive in a timely manner to Program Office requirements.

MUNICIPAL ENVIRONMENTAL RESEARCH LABORATORY

Cincinnati, Ohio


OFFICE OF THE DIRECTOR
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Deputy Director — L. W. Lefke
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Disposal Branch Chief: N. Schomaker
Processing Branch Chief: Dr. A. Klee
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Treatment Process Development Branch, Chief: Dr. R. L. Bunch
DRINKING WATER RESEARCH DIVISION
Director — G. G. Robeck
Microbiological Treatment Branch, Chief: E. Geldreich
Physical & Chemical Removal Branch, Chief: Dr. J. Symons

PROGRAM AND MANAGEMENT ANALYSIS

During 1976 and 1977, much time and effort was spent in forming and consolidating the programs of the Municipal Environmental Research Laboratory. In 1978 we were able to shift our Office of the Director resources from organizing and procedures development to program and management analysis. Major program areas covered were municipal sludge management, the toxics program and pathogen-virus research coordination with other ERC laboratories. In the management improvement area, the laboratory joined the ERC Personnel Office to undertake an intensive personnel management survey. A cost-saving and dissemination-effective computerized mailing list was tested and put into operation. These and many other management initiatives contributed to the continued success of managing an environmental research and development laboratory that is assigned about 10% of all ORD dollars and manpower.

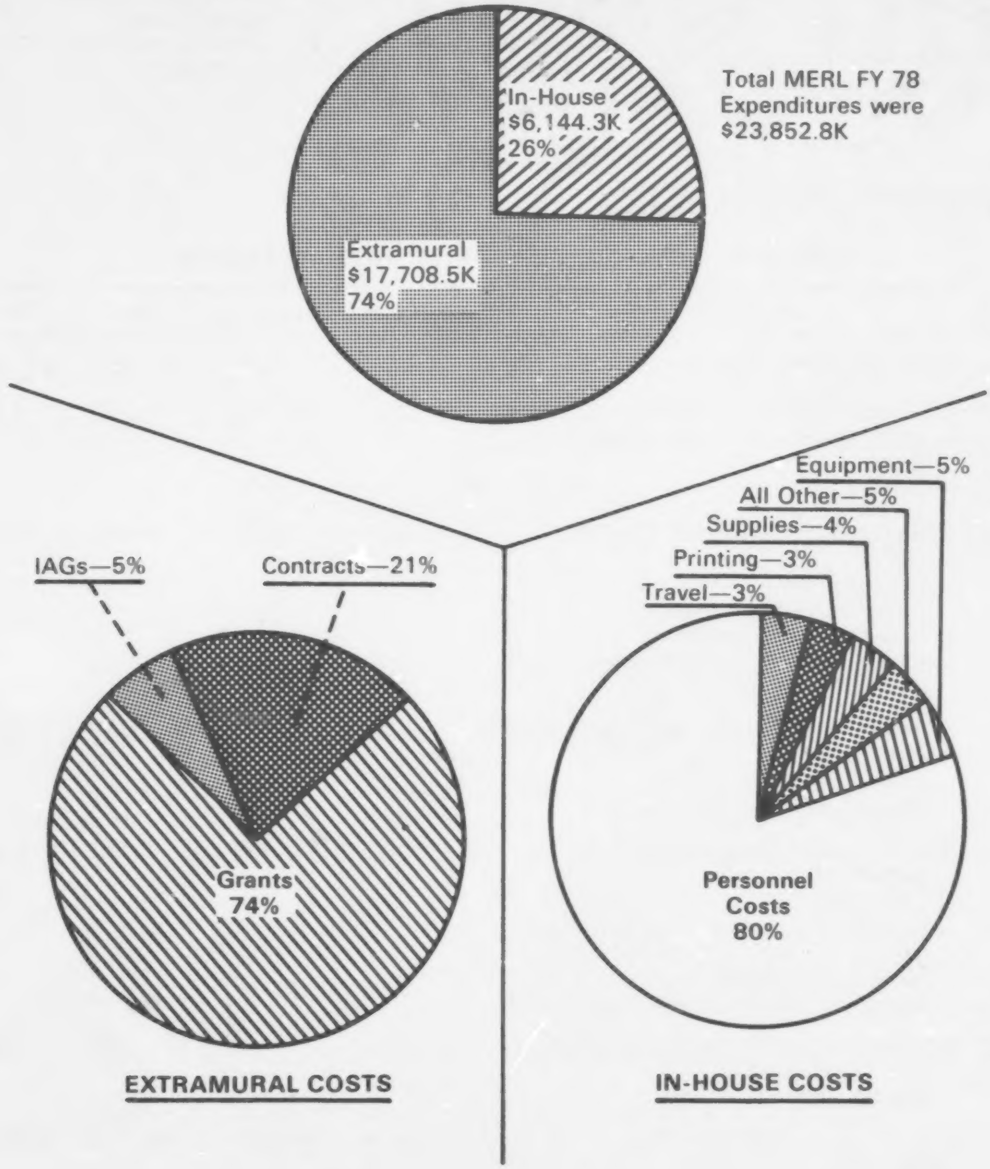
TABLE 1. MERL BUDGET FOR FY 1978 (IN $1,000'S)

PE #	AREA OF WORK	PFT POSNS.	IN-HOUSE $	XM $	TOTAL
1BC611	WASTEWATER TREATMENT TECHNOLOGY Combined Sewer Overflow Urban Stormwater Impacts Municipal Sludge Management O&M New Treatment Processes Municipal Wastewater Reuse Toxics Control Small Wastewater Flows	91	$3,045	$ 5,619	$ 8,664
1CC614	WATER SUPPLY TREATMENT & SYSTEMS MGMT. Physical And Chemical Contaminants Microbiological Contaminants	33	1,472	4,780	6,252
1DC618	SOLID & HAZARDOUS WASTE MANAGEMENT Land Disposal Waste Residual Disposal Alternatives Land Disposal Site Remedial Action Hazardous Materials Resource Recovery and Reuse	18	1,137	5,637	6,774
1HC619	ENVIRONMENTAL MANAGEMENT	5	165	309	474
1NE624	ENERGY-RELATED WASTE DISPOSAL Flue Gas Cleaning Wastes-as-Fuels	—	—	1,025	1,025
2CB656	WATER SUPPLY-TECHNICAL ASSISTANCE	14	325	—	325
2DB661	SOLID WASTE-OSW	—	—	305	305
XH1627	SOLID WASTE INTERAGENCY REIMBURSABLE	—	—	34	34
	TOTAL MERL	161	$6,144	$17,709	$23,853

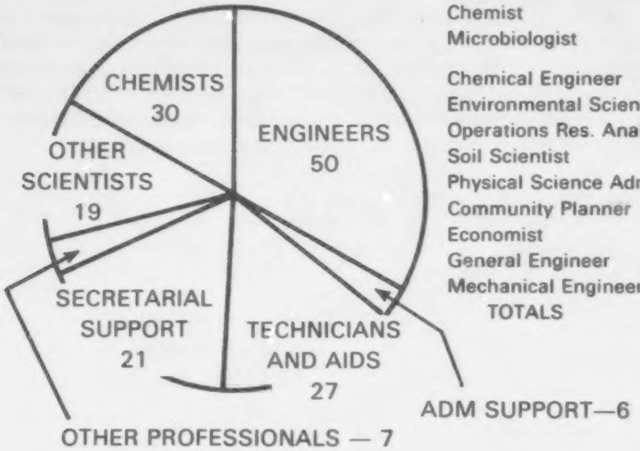
SUPPORTING THE RESEARCHERS

No laboratory can operate at a consistent high level of efficiency without a competent administrative support staff. The OD staff insures that the operating divisions have the resources they need to do their job by processing the documents necessary to obtain those resources. They expeditously handle purchase requisitions for supplies and equipment, personnel matters to promote adequate staff, financial matters to insure fiscal integrity, technical reports processing for information dissemination, and processing grants, contracts and interagency agreements packages to fulfill Agency and other requirements. In 1978 the OD installed a word-processing, shared-logic system to improve the timeliness and increase the efficiency of extramural commitment registers, work plans, and numerous other administrative documents.

WHERE THE MERL DOLLARS WENT IN FY 78



COMPOSITION OF MERL WORKFORCE BY DISCIPLINE (DECEMBER 1978)

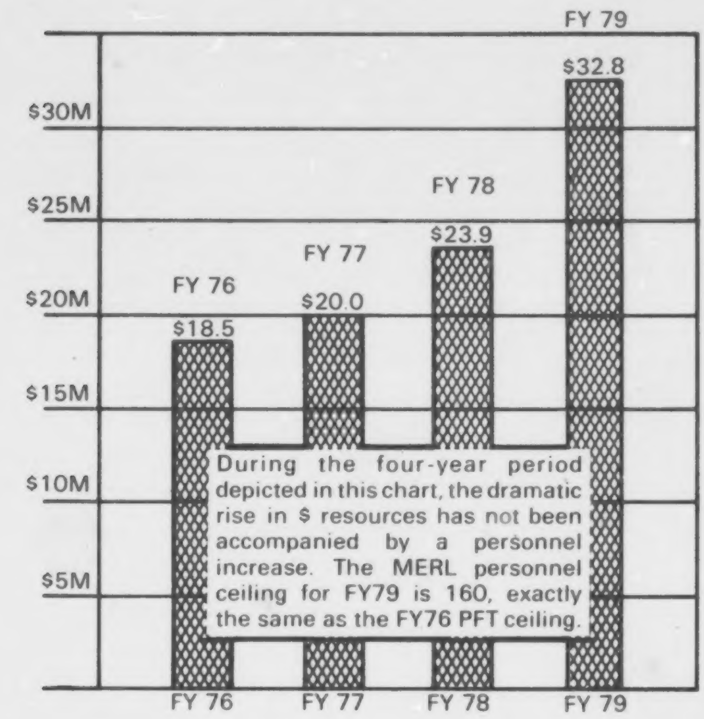


Professional Positions		Support Positions	
Environmental Engineer	40	Secretary	17
Chemist	30	Physical Science Aid/Tech	15
Microbiologist	10	Engineering Aid/Tech	7
Chemical Engineer	8	Biological Aid/Tech	4
Environmental Scientist	6	Typist/Steno	4
Operations Res. Analyst	3	Administrative Officer	1
Soil Scientist	3	Administrative Tech	1
Physical Science Adm	2	Editorial Assistant	1
Community Planner	1	Equipment Mechanic	1
Economist	1	Management Assistant	1
General Engineer	1	Program Analyst	1
Mechanical Engineer	1	Extramural Prog. Asst.	1
TOTALS	106	TOTALS	54

TABLE 2. MERL BUDGET FOR FY 1979 (IN $1,000S)

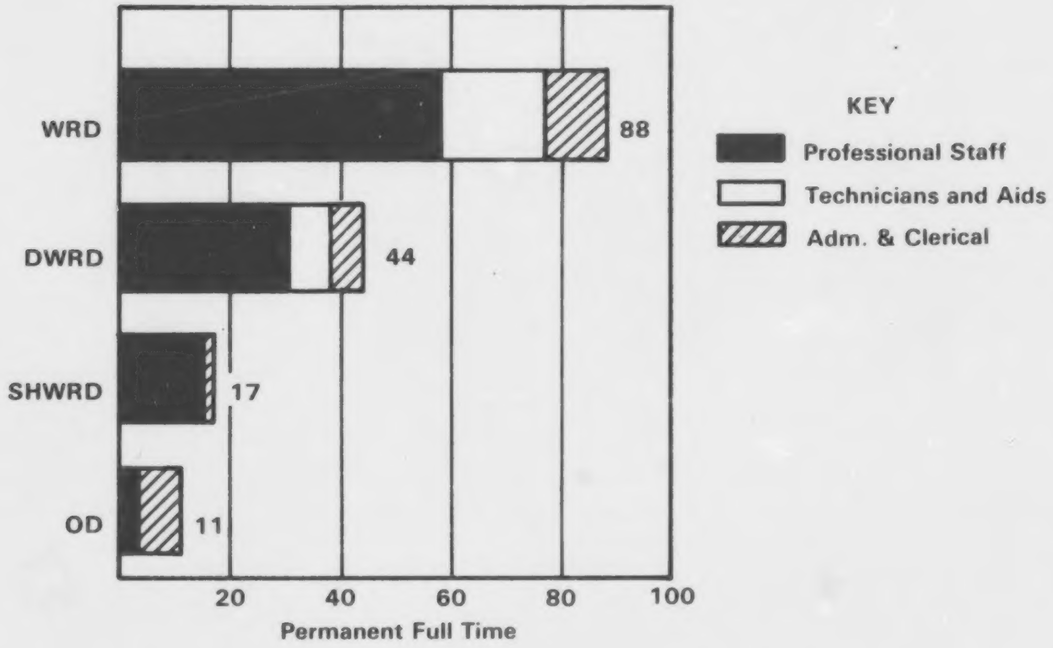
PE #	AREA OF WORK	PFT POSNS.	IN-HOUSE $	XM $	TOTAL
1AD712	CARBON FIBER RESEARCH	--	—	$ 600	$ 600
1BC821	URBAN SYSTEMS AND RESIDUALS MGMT. Municipal Sludge Management O&M Toxics Control	52	$1,913	4,350	6,263
1BC822	WASTEWATER SYSTEMS CONTROL TECHN. Combined Sewer Overflow Urban Stormwater Impacts New Treatment Processes Municipal Wastewater Reuse Small Wastewater Flows	45	1,562	11,559	13,121
1CC824	WATER SUPPLY TREATMENT & SYSTEMS MGMT. Physical and Chemical Contaminants Microbiological Contaminants	47	1,847	4,789	6,636
1DC818	SOLID & HAZARDOUS WASTE MANAGEMENT Land Disposal Waste Residual Disposal Alternatives Land Disposal Site Remedial Action Hazardous Materials Resource Recovery and Reuse	16	772	5,142	5,914
1NE827	ENERGY-RELATED WASTE DISPOSAL Flue Gas Cleaning Wastes-as-Fuels	—	—	265	265
	TOTAL MERL	160	$6,094	$26,705	$32,799

MERL RESOURCE TERMS

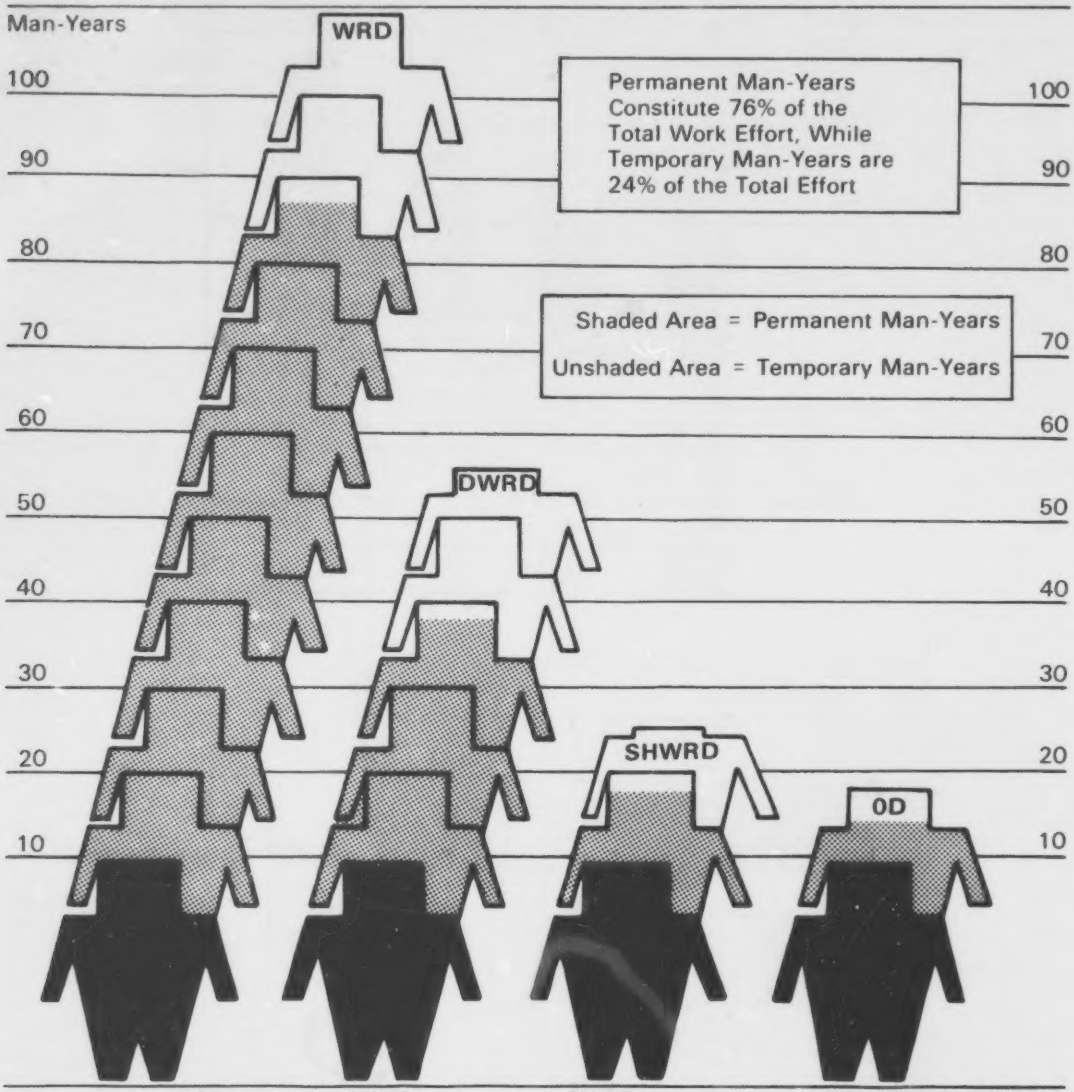


During the four-year period depicted in this chart, the dramatic rise in $ resources has not been accompanied by a personnel increase. The MERL personnel ceiling for FY79 is 160, exactly the same as the FY76 PFT ceiling.

Size and Composition of MERL Workforce by Organization (December 1978)



MAN-YEARS OF EFFORT FOR MERL IN FY 78



	WRD	DWRD	SHWRD	OD	MERL
PERM. M.Y.	87.0	38.9	16.4	13.2	155.3
TEMP. M.Y.	21.9	16.4	5.8	4.5	48.6
TOTAL M.Y.	108.9	55.4	24.2	17.7	203.9

SOLID AND HAZARDOUS WASTE RESEARCH DIVISION

The Solid and Hazardous Waste Research Division (SHWRD) conducts research in three major functional areas: disposal technology, hazardous wastes, and resource recovery. In the past, solid waste research was concentrated on problems associated with municipal solid waste. With present efforts directed primarily toward the environmental effects of hazardous waste disposed onto or into the land our research has concentrated on disposal or treatment technologies that will minimize or prevent harmful effects.

The problems of solid waste disposal are interrelated with those of air and water pollution. Incineration, grinding, the use of water either for transportation of solids or as a solid waste sink—these impinge upon the concurrent attempts to purify the air and water environments. Additionally, the elimination of impurities from air or water effluents by such processes as separation, drying, or compaction, results in the generation of solid wastes—solids that, in turn, require disposal. Measures to reduce pollution or disposal of waste material must, therefore, be taken with full consideration of the effect on the overall environment—air, water, and land.

The solid waste problem is concentrated in densely populated urban areas. Refuse storage, collection, transportation, and processing directly and intimately affect some 80% of the population. The costs of waste handling, already severe, are rising. The loss of billions of tons of material to unreclaimed waste each year indirectly affect each consumer.

Even more threatening in terms of public health and environmental effects are the present disposal practices for hazardous wastes. Current estimates indicate that 30 to 35 million tons of hazardous wastes are disposed of to the ground with no controls, no records as to location, quantity, and composition. At the present time, proven techniques for large-scale disposal of most, if not all, hazardous wastes are not available and generators of these wastes have little incentive to expend resources for adequate management.

Municipalities and other governmental agencies need new and improved systems for storage, collection, and transportation of solid waste; improved technology or methodology for waste reduction; and criteria for site selection, design, and operation of landfills.

WASTE DISPOSAL

Increasing amounts of waste residuals are being directed to the land for disposal by landfilling. The waste disposal program of SHWRD has been designed to document and evaluate the potentially adverse environmental and public health effects that could result if precautions are not taken for handling the leachate and gas produced in the course of landfilling. This SHWRD research—encompassing state-of-the-art documents, laboratory analysis, bench and pilot studies, and full-scale field verification studies—will result not only in research reports and criteria and guidance documents for user communities, but also in a criteria data base for the development of standards as mandated by the recently enacted Resource Conservation and "Recovery Act of 1976." The current research activities as classified and discussed here are:

1. Waste Characterization/Decomposition
2. Pollutant Transport
3. Pollutant Control
4. Pollutant Treatment
5. Co-disposal
6. Environmental Assessment
7. Remedial Action for Inoperative Sites
8. Landfill Alternatives
9. Economic Analyses

WASTE CHARACTERIZATION/ DECOMPOSITION

Studies in this area involve collecting composition data on municipal and hazardous wastes from individual waste residuals and landfill disposal sites. The study objectives are to (1) quantify the gas and leachate production from current best-practice sanitary landfilling and (2) modify the landfill method to reduce the environmental impact of gas and leachate production in a positive and predictable manner. These objectives are to be achieved by construction and long-term monitoring of typical and simulated landfill cells (Figure 1) and investigation, development, and optimization of those factors that control gas, and leachate production. Results are expected only after longterm monitoring, due to the extremely slow reaction rates.

Standard Techniques

Procedures for analyzing contaminants in leachate samples are being developed, both specific to the wastes being studied and for general use. In studying the potential environmental impact of contaminants, a standard test is being planned to assess contaminants leached from a waste by water and other solvents, both initially and over time.

Waste Leachability

One study involves the determination of long-term gas and leachate generation characteristics by leaching 437 tons of municipal refuse and comparing the results to those obtained for monitoring 117-ton and 3-ton experimental landfills, all at the Boone County Field Site (BCFS) of USEPA. Leachate collected form the 437-ton BCFS landfill (Figure 2) has carried from the landfilled waste the following mass of contaminants: 16,600 kg COD; 1,000 kg Ca; 607 kg Cl; and 440 kg Na. Based on these results, the mass release of contaminants form landfilled refuse are estimated to be 63.1 gm COD/cap/day; 3.8 gm Ca/cap/day; 2.3 gm Cl/cap/day; and 1.7 gm Na/cap/day. The 5 day BOD of raw domestic wastewater has been estimated at 54 gm/cap/day.

Survival of poliovirus in landfill refuse was investigated at BCFS and the Center Hill Facility. Studies showed the presence of this virus in municipal solid waste in leachates when the waste was surcharged with large volumes of water. Poliovirus-seeded refuse samples were exposed to landfill conditions for 10 or more days but no poliovirus survived or was found in the leachate. The high ambient temperatures (air = 35°C; refuse = 59°C) were assumed to be the principal cause of virus inactivation.

Another ongoing leachability study deals with inorganic industrial waste in which there is no appreciable biological activity. Consequently, the chief mode of decomposition and pollutant release is solubilization and other strictly chemical/physical changes rather than the

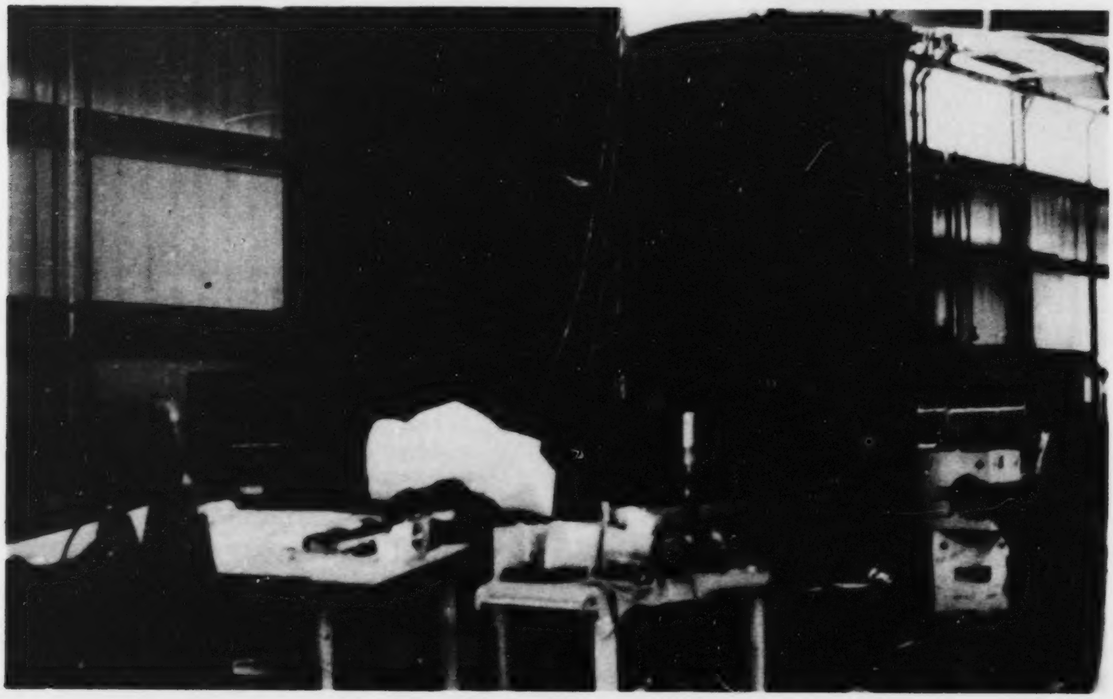


Figure 1. Experimental Landfills for Waste Decomposition Studies.

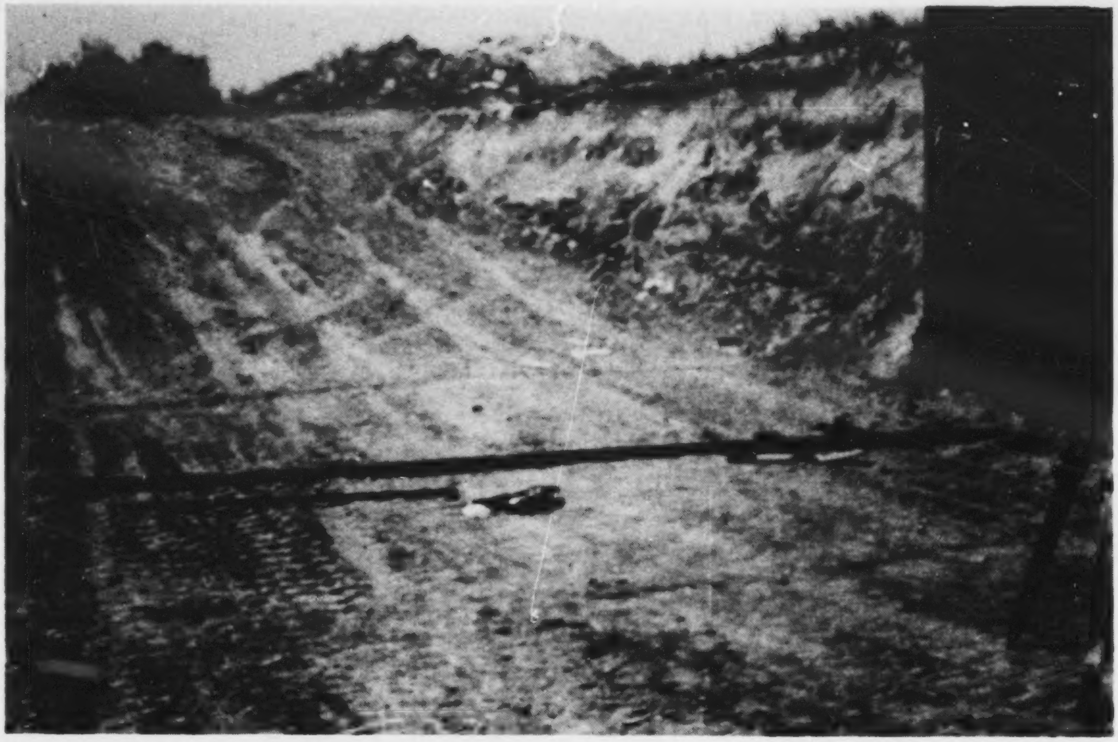


Figure 2. Construction of Leachate Collection System for the 437-Ton BCFS Experimental Landfill.

biological decomposition that takes place as the waste is leached with water. Accordingly, the testing program is designed to evaluate leaching and pollutant release through time under a variety of leaching conditions encountered in one or more disposal situations.

Results to date are consistent with findings from other projects that leachability of inorganic wastes is a function not only of the constituent of interest, but also of the surface area per unit weight of waste and the stability of the compounds formed during waste treatment. The variability in degree of buffering against solvent-induced changes dictates that the time dependent leachability also be considered. Figure 3 is a schematic of sequential leaching and sorption procedure being tested with the various inorganic wastes.

Waste Decomposition

A laboratory study is designed to examine the role of waste moisture content and net infiltration in waste decomposition (Figure 4). It has yielded information on the rates and duration of waste decomposition, including gas and leachate production.

It was found that increasing the moisture content of refuse increased the rate of gas production. A similar effect was also produced by increasing temperature and decreasing the size of the solid waste particles. Calculation of the activation energies indicated that the overall reaction rate was chemically controlled. The effective life of a landfill, during which gas can be extracted at a rate of 20 ml/kg dry wt./day was estimated to be 17 years after deposition. Increasing the rate of infiltration gas had only a minor effect on the total mass of contaminants leached from refuse; the rate of release, however, was found to be directly proportional to the rate of infiltration.

Also being studied are the effects of different waste processing techniques on gas and leachate production during waste decomposition. Raw refuse, shredded refuse, and baled refuse are being investigated in a simulated landfill environment. Processing of waste has been found to have very pronounced effects on the rate of contaminant mass leached from refuse. Baling appears to have very little effect on the rate of mass release, but shredding tends to accelerate the mass release of contaminants.

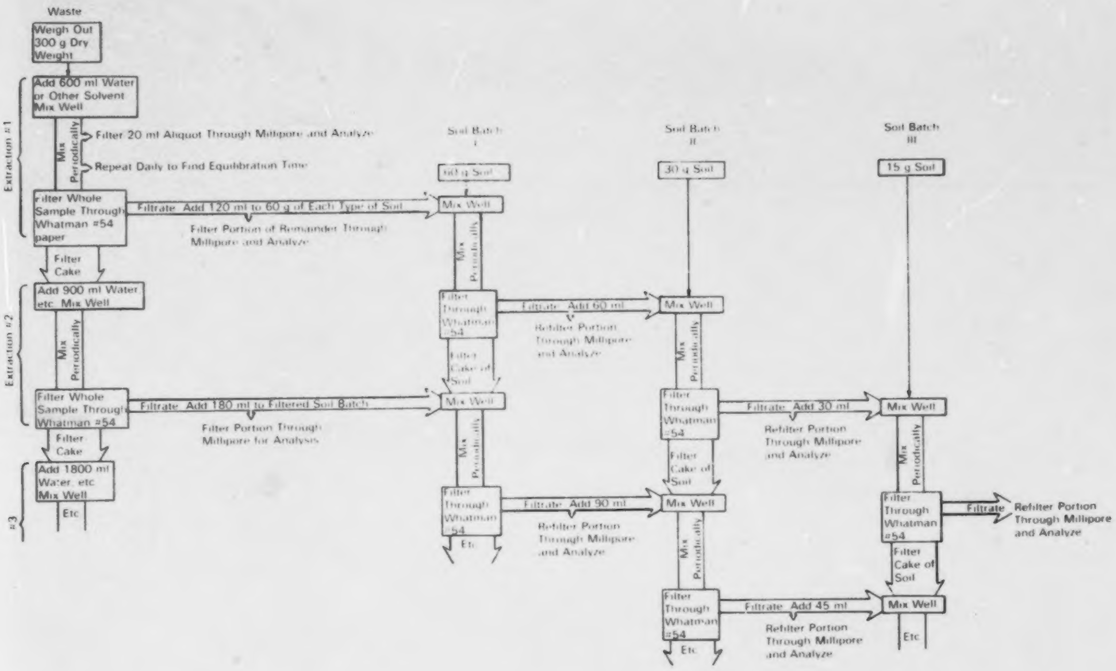

Waste
Weigh Out 300 g Dry Weight
Extraction #1
Add 600 ml Water or Other Solvent Mix Well
Mix Periodically
Filter 20 ml Aliquot Through Millipore and Analyze
Repeat Daily to Find Equilibration Time
Filter Whole Sample Through Whatman #54 paper
Filtrate Add 120 ml to 60 g of Each Type of Soil
Filter Portion of Remainder Through Millipore and Analyze
Filter Cake
Extraction #2
Add 900 ml Water etc Mix Well
Mix Periodically
Filter Whole Sample Through Whatman #54
Filtrate Add 180 ml to Filtered Soil Batch
Filter Portion Through Millipore for Analysis
Filter Cake
#3
Add 1800 ml Water, etc Mix Well
Etc
Soil Batch I
60 g Soil
Mix Well
Mix Periodically
Filter Through Whatman #54
Filtrate Add 60 ml
Refilter Portion Through Millipore and Analyze
Filter Cake of Soil
Mix Well
Mix Periodically
Filter Through Whatman #54
Filtrate Add 90 ml
Refilter Portion Through Millipore and Analyze
Etc
Soil Batch II
30 g Soil
Mix Well
Mix Periodically
Filter Through Whatman #54
Filtrate Add 30 ml
Refilter Portion Through Millipore and Analyze
Filter Cake of Soil
Mix Well
Mix Periodically
Filter Through Whatman #54
Filtrate Add 45 ml
Refilter Portion Through Millipore and Analyze
Etc
Soil Batch III
15 g Soil
Mix Well
Mix Periodically
Filter Through Whatman #54
Filtrate
Refilter Portion Through Millipore and Analyze
Filter Cake of Soil
Mix Well
Etc

Figure 3. Flow Chart for Graded Serial Batch Extraction.

POLLUTANT TRANSPORT

Pollutant transport studies examine the release of liquid and gaseous pollutants from various municipal and hazardous wastes and the subsequent movement and fate of these pollutants in soils adjacent to disposal sites. Although the potential for damage in general can be demonstrated, migration patterns of contaminants and consequent damages that would result from unrestricted landfilling at specific sites cannot be accurately predicted. The ability to predict must be developed in order to justify required changes in the design and operation of disposal sites, particularly for any restriction of co-disposal of municipal and industrial wastes. Both laboratory and field verification studies are being performed to assess the potential for ground-water contamination. The studies will provide the information required to (1) select land disposal sites that will naturally limit release of pollutants to the air and water and (2) make rational assessments of the need for and cost-benefit aspects of leachate and gas control technology.

The overall objective of this activity is to develop procedures for using soils as possible limiting or delaying media for the movement of pollutants. Consequently, a significant number of SHWRD-funded research projects focus on understanding processes and predicting the extent of migration of contaminants (chiefly heavy metals) from land disposal sites.

Controlled Laboratory Studies

One project is studying the movement in soils of contaminants present in landfill leachates, possibly introduced or increased in concentration by co-disposal of municipal and hazardous wastes. These contaminants are: arsenic, beryllium, cadmium, chromium, copper, cyanide, iron, mercury, lead, nickel, selenium, vanadium, and zinc.

The attenuation of the substances listed above was found to be a function of their individual properties and of the permeability of the soil and the amounts of clay, lime, and hydrous iron oxides present in the soil. Iron was also studied; its movement and retention were most closely correlated with the amounts of clay and hydrous iron oxides in soil. Amounts of elements retained by soils against subsequent extraction with water and 0.1 N HCl suggest substantial permanent retention capacity for soils. Total Organic Carbon (TOC) and Chemical Oxygen Demand (COD) in unspiked leachates were not significantly retained by any soils.

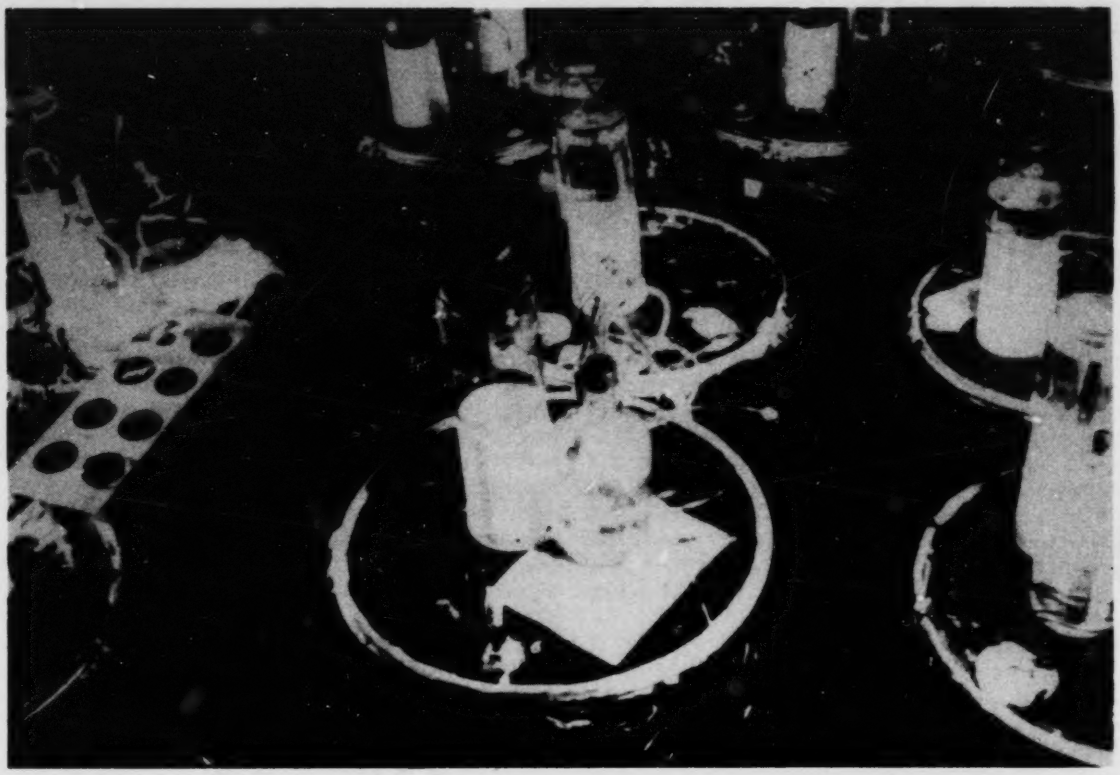


Figure 4. Bench-Scale 55-Gallon Experimental Landfill Lysimeters to Determine the Effect of Moisture Regime, Particle Size, and Temperature on Gas Production.

Another project is studying the removal of contaminants from landfill leachates by clay minerals. Columns were packed with mixtures of quartz sand and clay minerals. The leaching fluid consisted of typical municipal refuse leachate without metal salt additives. The general approach differed from that of the preceding project effort in that (1) both sterilized and unsterilized leachates were utilized to examine the effect of microbial activity on hydraulic conductivity and (2) batch studies of the sorption of metals from leachate by clay minerals were conducted. The column study results indicated that Cl, Na, and water-soluble organic compounds (COD) were relatively unattenuated by passage through the clay-sand columns; K, NH_4, Mg, Si, and Fe were moderately attenuated; and heavy metals — such as Pb, Cd, Hg, and Az — were strongly attenuated by even small amounts of clay. Concentrations of Ca, B, and Mn in the column effluents increased markedly over the original leachate concentrations.

Montmorillonite was found to have the highest attenuation capability, followed by illite and then kaolinite. Precipitation was found to be the principal attenuation mechanism for the heavy metals Pb, Cd, Hg, and Zn. The cation exchange capacity of the clay minerals was concluded to be the dominant attenuation mechanism responsible for the removal of other substances from the leachate.

The batch studies involved adsorption of Cr, Cu, Pb, Cd, Hg, and Zn by montmorillonite and kaolinite from water solutions and from landfill leachate. The adsorption in leachate proved to be 50 to 90% lower in most cases than the clays' adsorption capacity for the metal ions in pure aqueous solutions. Precipitation of the heavy metal cations was found to be an important attenuation mechanism while adsorption was the principal mechanism for the anions over the entire pH range studied. Pollutant adsorption by clay minerals (and hence the mobility of pollutants in clays and clay soils) was significantly affected by other, non-hazardous solutes in the leachates.

A model for predicting movement in soil of the landfill gases methane and carbon dioxide has been developed and used to evaluate several types of gas control procedures for protecting buildings adjacent to landfills. Generally, passive procedures such as gravel trenches are not as satisfactory as active procedures where air is pumped into or out of a trench or well. This model and its predictions are to be field tested during the next year. Another effort includes study of wastes from the following industries: electro-plating, inorganic pigments, water-based paints, nickel-cadmium batteries, chlorine, lead-acid batteries, carbon-zinc primary batteries, hydrofluoric acid, phosphorous, aluminum fluoride, titanium pigments, re-refining of used petroleum, and flue gas desulfurization. The potential for contaminant migration through soil from these wastes was being examined by the traditional soil column techniques. While these yielded useful information on soil contaminant interactions, the work was time consuming and difficult to replicate. As a consequence, sequential batch procedures have been developed and are being tested. The previous shown figure (Figure 3) illustrates how waste leachates and soils are contacted using these procedures.

In the area of organic contaminants, project results indicate that PCBs were immobile in all soils when leached with aqueous solvents (water and minicipal landfill leachate); they were highly mobile in all soil materials when leached with organic solvents. The rate of adsorption of PCBs by soil materials was found to be rapid, with equilibrium conditions achieved in less than 8 hours. The adsorption process conformed to the Freundlich adsorption equation. PCBs were found to be strongly adsorbed by soil materials. The adsorption capacity and the mobility of PCBs were positively correlated to the organic carbon content and surface area of the respective soil materials.

Other organic contaminant work studied the volatilization of hexachlorobenzene (HCB) out of wastes from manufacture of perchloroethylene and carbontetrachloride. Flux of HCB into the atmosphere could be controlled by soil covers compacted over landfills. Figure 5 is a flow diagram of the suggested process for designing a soil cover. The project also determined that the organic solvent fraction of the waste could be a significant source of HCB release.

Field Verification

Limited field verification is being conducted. The initial effort investigated the current assumptions about the effectiveness of clays and other fine-textured earth materials in restricting the movement of contaminants into groundwaters. This work examined patterns of contaminant migration around two secondary zinc smelting plants and an organic chemical manufacturing plant that are storing or disposing of wastes on land. The migration of metals (zinc, cadmium, copper, lead) that occurrred at the three smelters has been limited by attentuation processes to relatively shallow depths in the soil profile (≃ 12 feet). Cation exchange and precipitation of insoluble metal compounds were determined to be the principal mechanisms controlling the movement of metals through the soil. At the organic chemical manufacturing site, it appeared that the glacial materials were retarding the migration of organic pollutants. No organic pollutants were detected in the shallow groundwater system. Soil coring was found to be a useful tool, but not suitable by itself for routine monitoring of waste disposal activities.

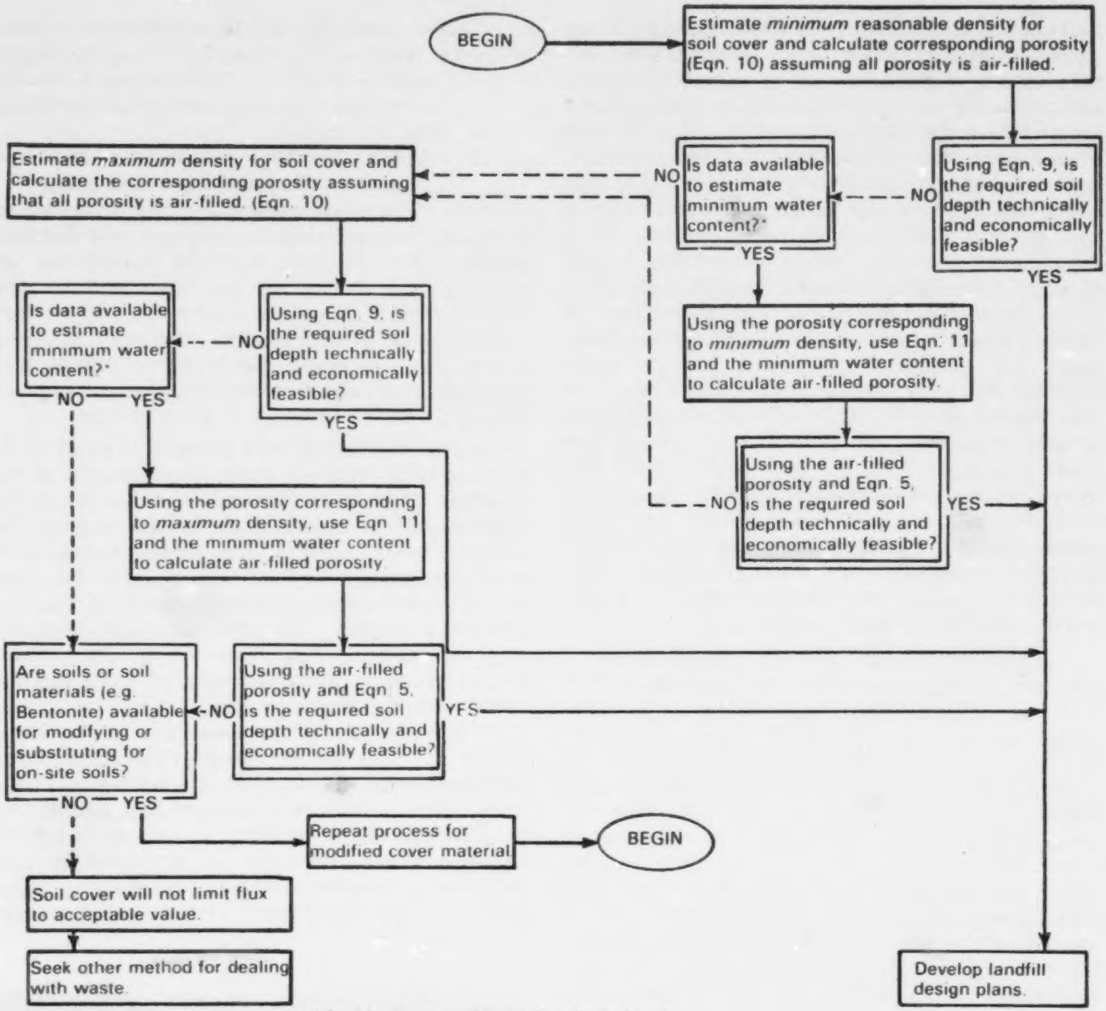
Another effort has consisted of installing monitoring wells and coring soil samples adjacent to three municipal landfill sites to identify contaminants and determine their distribution in the soil and groundwater. The sites represent varying geologic conditions, recharge rates, and age, ranging from a site closed for 15 years to a site currently operating. The results of the study indicated that changes in chemical composition of the groundwater could be related to the position of the borings with respect to the landfills. Water quality below and down the groundwater flow gradients showed increased levels of sulfate (all sites), nitrates, TOC, and cyanide. There were no changes in the soil physical parameters that could be attributed to the landfill. No evidence was found in this study to substantiate the idea that sub-landfill soils seal themselves.

POLLUTANT CONTROL

The pollutant control studies determine the ability of in-situ soils, ranging from sands to clays, and natural soil processes to limit the transport of leachate contaminants as the leachate migrates from landfill sites through the soil. The studies also determine how various synthetic and admixed materials can be utilized as liners to prevent leachate migration. The overall objective is to enable minimization of sub-surface pollution, particularly of groundwater.

Liners/Membranes/Admixtures

The test program will evaluate, in a landfill environment, the chemical resistance and durability of liner materials over 12-, 24-, and 36-month exposure periods to leachates derived from hazardous wastes, SO_x wastes, and municipal solid wastes. The liner materials being investigated for municipal solid wastes include six admixed materials.


BEGIN
Estimate *minimum* reasonable density for soil cover and calculate corresponding porosity (Eqn. 10) assuming all porosity is air-filled.
Using Eqn. 9, is the required soil depth technically and economically feasible?
NO
YES
Is data available to estimate minimum water content?*
NO
YES
Estimate *maximum* density for soil cover and calculate the corresponding porosity assuming that all porosity is air-filled. (Eqn. 10)
Using the porosity corresponding to *minimum* density, use Eqn. 11 and the minimum water content to calculate air-filled porosity.
Using the air-filled porosity and Eqn. 5, is the required soil depth technically and economically feasible?
NO
YES
Using Eqn. 9, is the required soil depth technically and economically feasible?
NO
YES
Is data available to estimate minimum water content?*
NO
YES
Using the porosity corresponding to *maximum* density, use Eqn. 11 and the minimum water content to calculate air-filled porosity
Using the air-filled porosity and Eqn. 5, is the required soil depth technically and economically feasible?
NO
YES
Are soils or soil materials (e.g. Bentonite) available for modifying or substituting for on-site soils?
NO
YES
Repeat process for modified cover material
BEGIN
Soil cover will not limit flux to acceptable value.
Seek other method for dealing with waste.
Develop landfill design plans.

*At this stage, could consider irrigation or other treatment to maintain higher water content (if allowed by regulatory agency).

Figure 5. Flow Diagram for Predicting Depth of Soil Cover Required to Limit Vapor Flux Through Soil Cover to an Acceptable Value.

- 2 asphalt concretes (varying in permeability),
- 1 soil asphalt,
- 2 asphalt membranes (one based on an emulsified asphalt and the other on catalytically-blown asphalt),
- 1 soil cement;

and six flexible membranes:

- butyl rubber,
- ethylene propylene rubber (EPDM),
- chlorinated polyethylene (CPE),
- chlorosulfonated polyethylene (HYPALON),
- polyethylene (PE), and
- polyvinyl chloride (PVC).

Results of the first 12 month's exposure to municipal solid wastes produced only minor changes on the physical properties of the liner materials exposed to landfill leachate. With the exception of polyethylene and ethylene propylene diene monower, all liner materials had small losses in tensile strength. The heat sealed seam retained their strength the best while some major losses were observed in other seaming techniques. In all cases the liner materials softened. None of the polymeric materials allowed leachate to pass during the first year exposure although leakage was observed through the soil asphalt and asphalt concrete liner materials. Liner materials for hazardous waste disposal sites will be tested in rectangular, epoxy-coated steel cells (25 cm by .38 cm), with about 30 cm of hazardous waste above the material being tested. A number of polymeric membranes and admixed materials are under consideration for study as primary liner materials. The first year's results of liner materials exposed to hazardous wastes produced some drastic changes in the asphaltic type liners. Strong acid and a strong base caused these asphaltic liner materials to fail. Strong acid also caused the soil cement type liner to fail. The effects of the wastes upon the polymeric membrane linings varied considerably with the polymer and the waste. Oily type wastes generally degrade flexible membranes unless specifically compounded to contain this class of wastes. Although the results of the first year's exposure must be considered preliminary, it is quite apparent that some of the hazardous wastes used in this study can seriously affect the physical properties of lining materials. This reinforces the concept of testing specific liner and waste combinations for compatibility.

The final liner study involves materials for sites receiving sludges generated by the removal of sulfur oxides (SO_x) from flue gases of coal burning power plants and will differ from studies for municipal and hazardous waste. Methods of lining such disposal sites must have a low unit cost, and materials should be easy to apply. Because of these considerations, fewer polymeric membranes have been included in the study, the emphasis being on admixed and sprayed-on materials. Results to date at the midpoint of the study indicate that two of the admixed liners (M179 and Guartec) had disintegrated due to reaction with the sludge. The sludge which was thought to be an acceptable liner material itself did not act as a liner nor did it seal the soil as expected.

Chemical Stabilization

Chemical stabilization is achieved by incorporating the solid and liquid phases of the waste in a relatively inert matrix that protects the components of the waste from dissolution by rainfall or other water in the soil.

If this slows the rate of contaminant leaching sufficiently to render the waste essentially harmless, then restrictions on disposal site location can be minimal. The test program consists of investigating five industrial wastes, in both the raw and fixed states. Each waste was treated in five separate fixation processes and subjected to physical testing for leachability. Results to date indicate that leaching of fixed wastes is a function of physical, chemical, and biological mechanisms and principally occurs in the following two ways:

1. External leaching which occurs primarily as surface washing and/or as diffusion into surface flow.
2. Internal leaching which is primarily a function of the solubility of the material.

Since most fixed wastes are characterized as being highly impermeable; then in a field disposal situation the internal leaching contributes an insignificant mass of contaminants to the environment. External leaching is the predominant mechanisms for contaminant mobility from fixed waste disposal areas. As primarily stated, this external leaching is a combination of surface washing and/or diffusion to surface flow.

Fixation of sludges will generally result in an improvement in leachate quality because of the inherent physical and chemical properties of the fixed wastes as compared to the raw sludges. The primary factor contributing to improvement in leachate quality from fixed wastes is the reduction in raw waste surface exposed to leaching. This fact generally results, not only in lower leachate concentrations, but also in a significant improvement in the total mass of contaminants released to the environment.

Co-disposal of the fixed waste with municipal refuse is also being investigated. Chemically stabilized industrial sludges have been loaded into large lysimeters with municipal solid waste (Figure 6). These lysimeter systems will simulate landfill conditions. Differences in leachate quality between untreated sludges, stabilized sludges, and MSW without sludges are being determined.

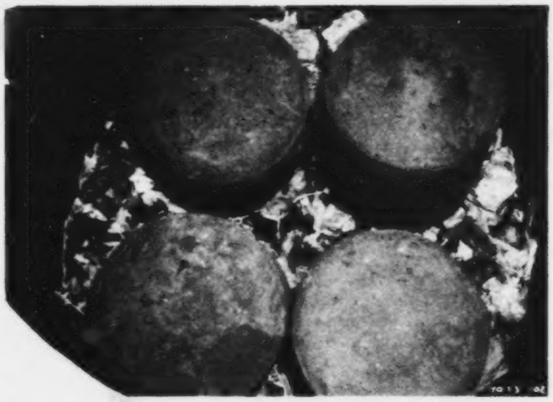


Figure 6. Chemically Stabilized Sludge Placed Into a 6-Foot Diameter Simulated Landfill Lysimeter.

POLLUTANT TREATMENT

The pollutant treatment studies relate to physical, chemical, or biological treatment of collected leachate prior to discharge from the landfill site. The overall objective is to develop technology that treats the landfill leachate after collection and containment at the landfill site.

Physical-Chemical Treatment

Physical-chemical treatments tested in the laboratory include chemical precipitation, activated carbon adsorption, and reverse osmosis. The activated carbon was quite effective in removing refractory organics in the effluent of biological treatment systems. In general, physical-chemical treatment processes have been found to be most effective in polishing the effluent from biological systems treating municipal landfill leachate and in treatment leachate from stabilized old landfills.

An ongoing laboratory study is evaluating various materials that could be utilized to retard or minimize migration of pollutants from disposal sites. Agricultural limestone, hydrous oxides of iron (ferrous sulfate mine waste), lime-sulfur oxide (stack-gas waste), and certain organic waste are included in the studies. Results to date indicate that linings of crushed limestone retard movement of metallic, cation-forming trace elements more effectively than anion-forming trace elements. MSW leachate characteristics influence the effectiveness of limestone linings. Information to date is not sufficient to design a lining to "treat" a given amount of leachate. Though effective in retardation, hydrous iron oxides may create additional problems due to the release of reduced iron.

Biological Treatment

Various biological processes have been studied in the laboratory for the treatment of leachate. The process kinetics, the nature of the organic fraction of leachate, and the degree of treatment that may be obtainable using conventional wastewater treatment methods have been investigated. The biological methods evaluated were the anaerobic filter, anaerobic and aerated lagoons, and combined treatment of municipal landfill leachates and municipal sewage using activated sludge. Biological units were operated successfully without prior removal of the metals. Leachate from recently constructed landfills was best treated by aerobic or anaerobic, biological treatment processes.

CO-DISPOSAL

Presently, little is known of the effects of co-disposal (industrial waste with municipal solid waste) on the decomposition process and the quantity and quality of gases and leachate produced during decomposition in landfills. There is a strong concern that the addition of industrial wastes to municipal waste landfills will result in elevated metal concentrations in the leachates and, potentially, in groundwaters. Advocates of co-disposal believe that the presence of organics in the landfill will immobilize heavy metals and that the presence of industrial sludges may accelerate the decomposition process and shorten the time required for biological stabilization of the refuse. Because of the high moisture content and, commonly, the high pH and alkalinity of these sludges, periodic analyses of the leachates for trace and heavy metals over a long period will be required to provide data to allow rational evaluation of co-disposal. The objective is, ultimately, to predict the patterns of chemical and microbiological transformations involving such contaminants.

The initial effort involves a study of the factors influencing the effect of admixing industrial sludges and sewage sludge with municipal refuse. A combination of municipal solid waste and various solid and semi-solid industrial wastes was added to several field lysimeters (large-scale test cells). All the contents were measured and characterized to obtain relations to leachate quality and quantity, gas production, and microbial activity. Results of this ongoing effort have yielded the following observations:

1. The addition of sewage sludge to landfilled municipal refuse may enhance the rate of mass release of organic matter if less than per capita equivalent production quantities of sludge are added. At equivalent per capita production, no difference has been noted.
2. No great differences in the rate of contaminant mass release by leaching has been noted for inorganic pigment waste.
3. Addition of electroplating waste increased the mass flux of COD, total solids, Cl, Cu, Cr, and Ni.
4. Heavy metals and salt mass flux resulting from the addition of chlorine production sludge were noticeably greater than from refuse only.
5. Heavy metals were leachated in greater quantities when electroplating waste was disposed with municipal refuse.
6. A decrease in the mass flux of contaminant was noted when biologically active petroleum sludge was added to refuse.

A second effort involves the leaching of industrial wastes using municipal landfill leachate and water. Results to date indicate that municipal landfill leachate solubilizes greater amounts of metals from the wastes and promotes more rapid migration of metals through soil than does water. Studies on industrial wastes, coal flyash, and sludges generated by removing sulfur oxides from power plant flue gases are being planned as a continuation of this project.

A study to evaluate co-disposal of chemically stabilized sludges in a municipal refuse landfill is also under way and was discussed under the chemical stabilization section.

ENVIRONMENTAL ASSESSMENT

Studies of the environmental effects of waste disposal to the land in relation to management and disposal practices for municipal solid wastes have been initiated. The overall objective is to enable the prediciton of environmental effects.

Vegetative kills and growth problems associated with landfill gas migration have been evaluated. Additional investigations will determine measures for reducing vegetation losses and those vegetation species best suited to landfill environs.

Another project is determining the important of milled refuse particle sizes for a landfill operated without daily cover. The overall objective is to establish operation and maintenance parameters to minimize detrimental environmental effects. Variables to be evaluated are: the effect of wind velocities and direction on the movement of landfilling material; the amount of differential settling associated with size variations; the initial and subsequent densities with relation to time and consolidation within each test cell and the presence or absence of surface crusting; nuisance organisms, wildlife, and the type and amount of plant growth; and odors and background conditions potentially responsible for odors.

REMEDIAL ACTION FOR INOPERATIVE SITES

The Office of Solid Waste has recently concluded the investigation of 391 damage cases traceable to waste disposal. Fifteen percent of these cases involved groundwater pollution from hazardous waste landfills, 25% involved groundwater pollution from indiscriminate dumping practices, and 40% involved leachate problems. Nine percent or 35 of the 391 damage cases, involved well pollution. In order to determine the best practical technology and economical corrective measures to remedy these pollution problems, a research effort to provide users with the descriptions and costs of corrective measures has been initiated. Phase I will be an engineering feasibility study that will determine on a site-specific basis the best applicable existing neutralization or confinement techniques. Phase II will determine the effectiveness, by actual field verification, of Phase I. Phase III will provide a site remedial guide to local municipalities and users. The Phase I effort has produced a guidance manual to assist user communities in the selection of available engineering technology to reduce or eliminate leachate generation at inoperative landfills. Five categorical areas are discussed. Surface water control, groundwater control, plume management, chemical immobilization and excavation/reburial.

LANDFILL ALTERNATIVES

Although municipal solid wastes are normally incinerated or deposited in standard sanitary landfills, other options are necessary for more hazardous materials. Among the alternatives being considered are: (1) deep well injection, (2) underground mines, (3) land cultivation, and (4) saline environments. Alternatives 1 and 2 are primarily orientated toward hazardous wastes.

Deep Well Injection and Underground Mines

Available information has been compiled on the injection of industrial hazardous wastes into deep wells and the placement of such wastes in underground mines. Results of the latter study showed that a majority of the nonradioactive hazardous wastes considered can be acceptably stored if properly treated and containerized. In the United States, room and pillar mines in salt, potash, and gypsum appear to be most favorable for storage. Systems adequate to detect, monitor, and control waste migration are available or can be developed from current technology.

Land Cultivation and Saline Environments

The disposal technique of land cultivation, whereby specific waste residues have been directly applied or admixed into soils, has been an alternate disposal option for many years by pharmaceutical, tannery, food processing, paper and pulp, and oil refinery industries. To assess this concept, various research efforts have been initiated. The initial state-of-the-art document indicated that application of shredded municipal refuse or compost to marginal or drastically disturbed land improves soil structure and fertility, thus making revegetation possible. It appears that the environmental pollution caused by land cultivation is minimal as compared to that for landfills, primarily due to maintenance of aerobic conditions and the lower concentration of waste per unit area of land.

The second effort is a combination laboratory, greenhouse and field study to determine the fate and mobility of wastes in soil for the purpose of developing criteria for use in the design, management and monitoring of land cultivation disposal operations. Decomposition rate, application rate, plant survival and growth, pollutant runoff and leachate generation will be obtained in development of data base.

The third effort relates to detailed field surveys and limited laboratory field experimentation for the purpose of developing a matrix of industrial organic and inorganic and municipal waste streams versus operational parameters. This matrix of information will be used to develop design and guideline criteria.

Information available on the disposal of municipal solid waste in saline environments, i.e., estuaries and coastal marchlands, is also being obtained. Case studies will be collected and state regulations and policies will be compiled for those states bordering saline waters. The effort is primarily a paper study detailing the present environmental and economic status of this type of disposal option.

ECONOMIC ANALYSES

The use of market-oriented incentive (disincentive) mechanisms has received very scant consideration for pollution control policy in the United States, particularly in the area of hazardous waste management. Economic theory suggests that incremental pricing of waste collections and disposal would reduce the waste generation rate, enhance source separation of recyclable materials, accelerate technological innovation, and minimize total system cost.

The economic relevance is being addressed hazardous waste management in general and the environmental impact aspect is being addressed to flue gas cleaning (FGD) sludge disposal.

In the economic relevance effort currently being investigated, a methodology is being developed that permits economic and social impacts of alternative approaches to hazardous waste management to be addressed. The procedure involves generation of a series of environmental threat scenarios that might arise from the use of different hazardous waste management techniques. The costs attributable to any technique comprise the control costs, and the environmental costs and benefits together determine the net benefits associated with the threat scenarios.

In the environmental impact effort the problem of FGD sludge disposal to the land has been addressed. This effort considered the problem from a potential regulatory approach by evaluating the existing data base and projecting its potential impact on the promugation of sludge disposal regulations.

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RESOURCE RECOVERY

SHWRD is charged with the responsibility for (1) resource recovery research and development (including materials and energy recovery), (2) waste reduction, and (3) hazardous materials treatment and processing. The multifaceted resource recovery programs involve research to determine and develop the best techniques for the recovery and reuse of the material and energy values contained in municipal solid waste. Currently, the program involves research in seven basic areas:

1. Refuse Derived Fuels
2. Evaluation of Resource Recovery Facilities
3. Technology Assessment
4. Process Equipment Evaluations
5. Selected Waste Utilization
6. Environmental Impacts
7. Special Studies under the Resource Conservation and Recovery Act (PL 92-580)

REFUSE DERIVED FUEL

This research involves extracting the combustible organic fraction of municipal solid waste, processing it into an easily handled form, and investigating its combustion characteristics in industrial, institutional, and utility boilers. Research priorities include co-firing of refuse derived fuels (RDF) and coal; investigating chemical and thermal processes for improving RDF fuel quality; onsite combustion tests to determine environmental emissions, plant modifications, and equipment requirements; development of standard sampling and testing procedures, and specifications for a standardized RDF and d-RDF (densified). With increasing experience and knowledge, the marketability and acceptability of RDF should improve, making it a promising resource recovery alternative.

SHWRD is cooperating with others to help increase the acceptability of the concept. Cooperative projects are being implemented with the EPA Industrial Environmental Research Laboratory (IERL) in Cincinnati to evaluate special aspects of the Madison and Milwaukee, Wisconsin resource recovery systems dealing with the use of RDF. Additionally, IERL and SHWRD are cooperating with the State of Maryland in a project to use RDF as a fuel in cement kilns. The State of Maryland also cooperated with SHWRD in the first phase combustion test of densified refuse derived fuels in the Maryland Correctional Institute's stoker boiler located near Hagerstown, Maryland. Industry is also cooperating as the second phase tests of d-RDF will be conducted in an industrial boiler located in Erie, Pennsylvania. To further this cooperation, SHWRD provided 60 tons of d-RDF to be tested at a state boiler in New York. SHWRD also conducted studies jointly with the Department of Energy to provide information on mixing techniques for the anaerobic digestion of mixtures of solid waste and sewage sludge for producing methane gas.

RESOURCE RECOVERY FACILITIES

Several research projects are directly concerned with the design, implementation, testing, and evaluation of planned or existing resource recovery facilities.

The City of Ames, Iowa received a grant from SHWRD to evaluate the city resource recovery system. Research includes statistically designed experiments to investigate air emissions from RDF combustion, boiler corrosion, burnouts, and boiler and plant operations. Figure 7 diagrams the sampling points on the stoker-fired boilers at the Ames facility.

The project is providing the first long-term data available on the effects of RDF on the corrosion of boiler tubes. Tubes placed in situ have been removed after 1,000 hours and 1 year of exposure to the combined combustion of RDF and coal. Analyses have indicated virtually no corrosion for the 1,000 hour samples and while only preliminary, the results appear the same for the year-exposed samples. The project is currently being managed by IERL-Cincinnati.

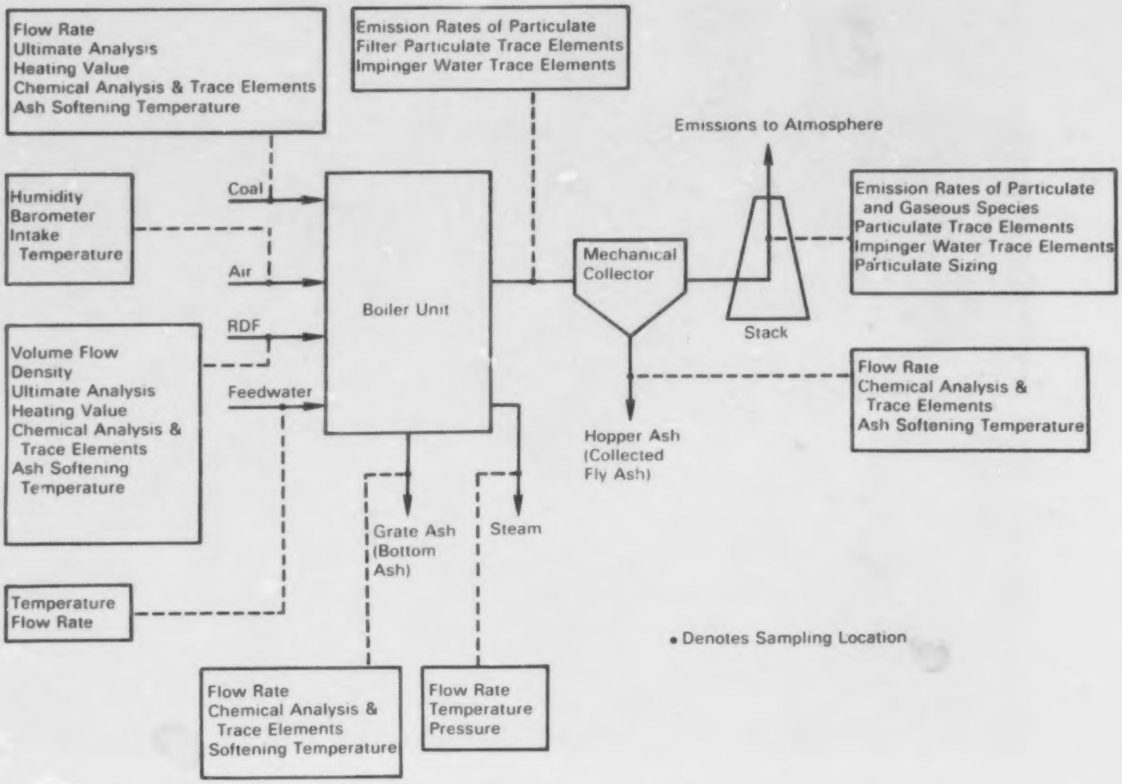
Flow Rate
Ultimate Analysis
Heating Value
Chemical Analysis & Trace Elements
Ash Softening Temperature
Emission Rates of Particulate
Filter Particulate Trace Elements
Impinger Water Trace Elements
Emissions to Atmosphere
Humidity
Barometer
Intake Temperature
Coal
Air
RDF
Feedwater
Boiler Unit
Mechanical Collector
Stack
Emission Rates of Particulate and Gaseous Species
Particulate Trace Elements
Impinger Water Trace Elements
Particulate Sizing
Volume Flow
Density
Ultimate Analysis
Heating Value
Chemical Analysis & Trace Elements
Ash Softening Temperature
Flow Rate
Chemical Analysis & Trace Elements
Ash Softening Temperature
Hopper Ash (Collected Fly Ash)
Grate Ash (Bottom Ash)
Steam
Temperature
Flow Rate
• Denotes Sampling Location
Flow Rate
Chemical Analysis & Trace Elements
Softening Temperature
Flow Rate
Temperature
Pressure

Figure 7. Boiler Unit Sampling Locations at the Ames, Iowa Solid Waste Recovery Facility.

To complement the completed St. Louis Refuse Processing Plant Study, sampling and analysis for selected indicator organisms and viruses, including potential pathogens, were performed. The results showed that airborne bacterial levels, both in-plant and at the property line, are generally higher for refuse processing plants than for wastewater treatment plants, refuse collection vehicles, and a number of other waste handling facilities that were also tested. Concurrent tests, however, have shown that these emissions can be controlled with fabric-filters.

SHWRD has conducted several projects to develop facility-design data, including alternative disposal systems and methods for predicting waste composition and quantity. A study of the Palos Verde, California landfill involved optimizing methane production from the landfill and testing biodegradation processes and rates.

An additional study further defined the state-of-the-art of methane recovery from landfills and assessed the technical and economic feasibility of the concept. The concept is technically feasible, but economical only under specific circumstances. Off-site sales of raw (low BTU) gas to industrial customers is profitable under current market conditions if a minimum production volume can be guaranteed. Sales of cleaned gas (medium to high BTU) to utilities is economical only in specific cases. With the deregulation of natural gas, however, this concept will likely be attractive in most cases. Figure 8 shows the landfill gas processing facilities in operation at Mountain View, California.

TECHNOLOGY ASSESSMENTS

In addition to the data being generated from evaluation of available resource recovery facilities, studies are being conducted to assess the feasibility of alternative technologies for resource recovery.

The biological conversion of cellulosic wastes to methane is being studied at two commercially constructed, intermediate-sized digesters. The results of this techno-economic assessment will

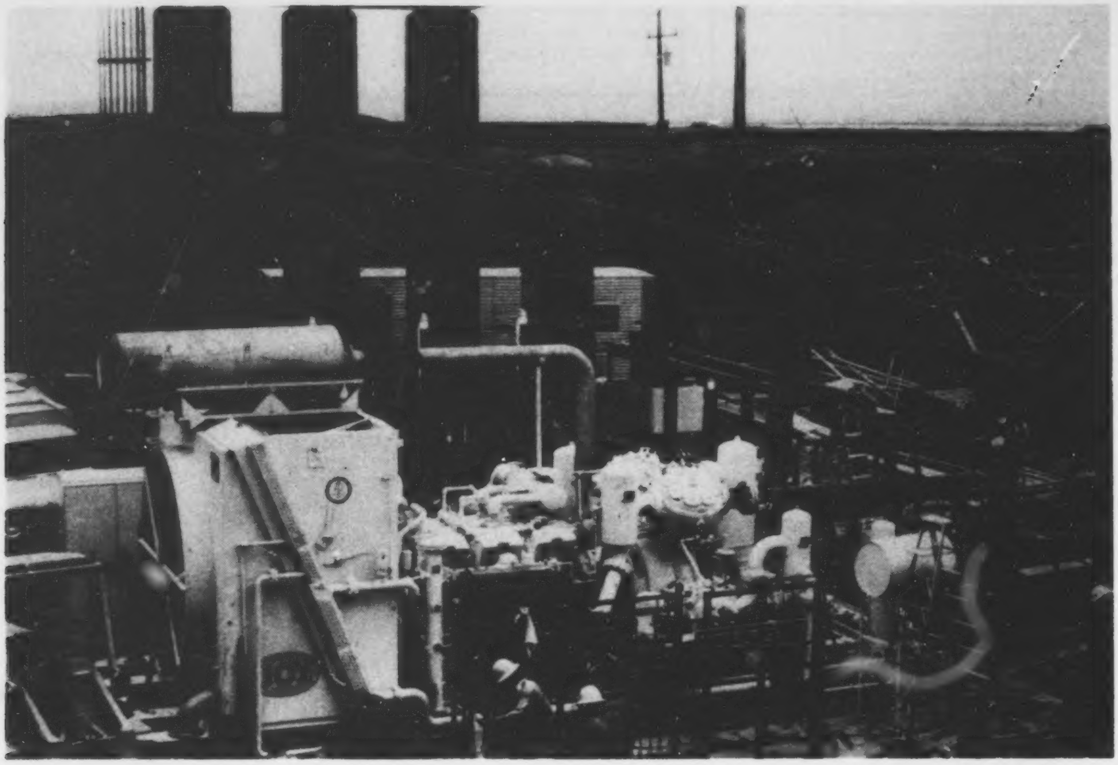

Figure 8. Landfill Gas Recovery Facilities at Mountain View, California.

determine the feasibility of producing methane from agricultural waste in rural communities.

Research was continued to successfully scale the laboratory-scale acid hydrolysis process to a 1-ton/day continuous pilot plant process. This process converts cellulose to glucose. The studies have determined the temperatures, pressures, acid injection rates, and other factors necessary for successful conversion of cellulose to glucose on laboratory scale. Continuing studies are also optimizing the biochemical process to produce methane rather than ethyl alcohol from glucose, since indications are that the methane can be produced more effectively and lends itself readily to successful marketing.

Three techniques have been developed and evaluated on the laboratory scale for utilization and stabilization of pyrolytic oils produced from municipal solid waste. Physical and chemical processing steps are being investigated to maximize the value of the oils produced and to maintain their consistency during storage. Evaluations of the processes are continuing to select the most promising process for scale-up studies. The process of choice will be scaled to 50 lb/day continuous process.

Related studies have identified and verified chemical treatments for cellulose embrittlement. As a result, the basic requirements were defined for producing a fine powdered RDF from the organic fraction of municipal solid waste.

Another study analyzed 16 small-scale and low-technology resource recovery systems and selected seven for further detailed evaluation as techniques for use by small waste generators. Based upon study criteria, it was determined that modular incineration with energy recovery and source separation were the most feasible and most promising approaches.

PROCESS EQUIPMENT EVALUATIONS

Several projects are being conducted to evaluate the operating performance of selected types of resource recovery process equipment. The shredders at several large-scale solid waste processing facilities are being evaluated to determine their performance characteristics as well as to verify basic theoretical relationships developed in laboratory research on the size reduction of solid waste. The shredder at the Ames, Iowa Resource Recovery Facility (Figure 9) is one of the units being tested.

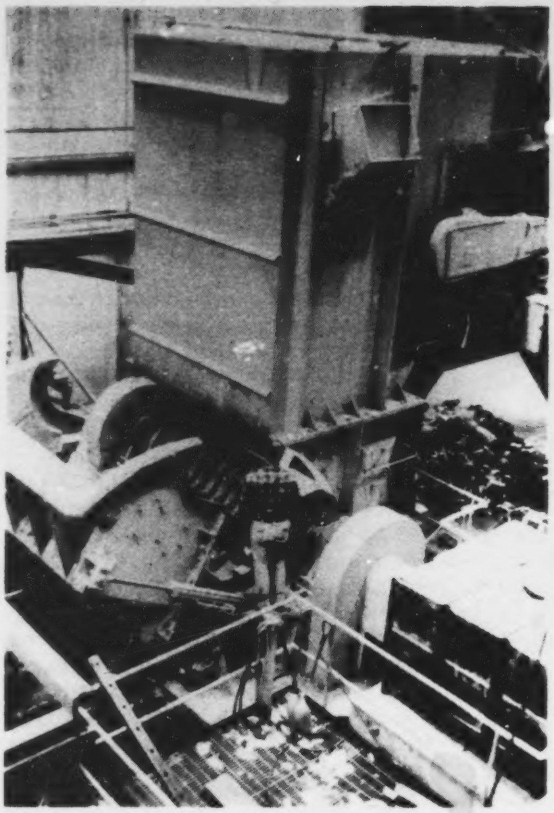

Figure 9. Shredder at the Ames, Iowa Resource Recovery Facility.

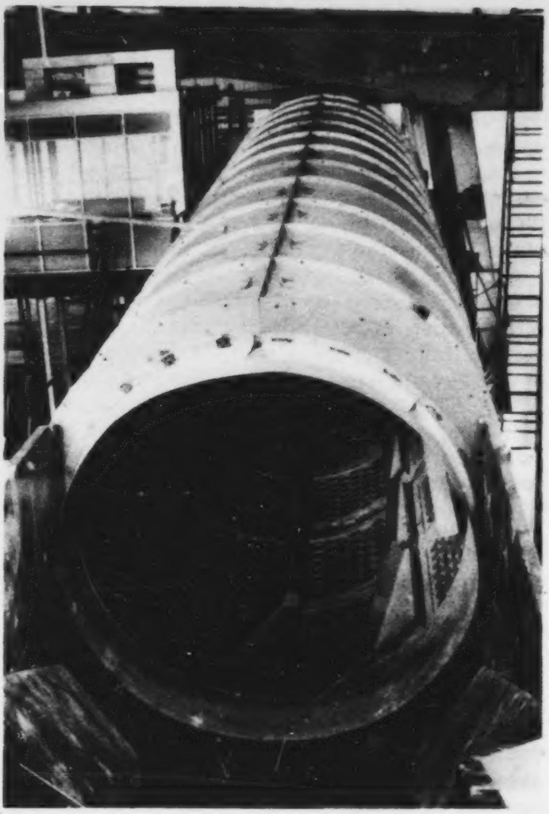

Figure 10. Interior of the Trommel Screen at Recovery I.

Another study is evaluating the operating performance of large-scale air classifiers. Separate studies are characterizing the froth filtration process for separating glass and the use of a trommel to classify the waste prior to shredding. The use of rotating cylindrical trommel screens prior to shredding may offer advantages such as reducing unwanted fines in RDF, reducing shredder wear, and generally improving the recovery of materials from solid waste. The interior of a full-scale trommel is shown in Figure 10.

A more basic research project is investigating equipment for densifying solid waste to produce d-RDF. Attempts are being made to develop the basic data required to design proper equipment and processes for the production of d-RDF. Studies are being coordinated with other projects currently producing d-RDF pellets for combustion tests.

SELECTED WASTES UTILIZATION

Several components of municipal solid waste have been identified as especially suitable for recovery and reuse. One component examined in several applications is discarded automobile tires and scrap rubber. A study has identified the costs and benefits of alternative scrap tire management methods, including use in rubberized asphalt, retreading, energy recovery through incineration, and landfilling. Technical parameters are being assessed; e.g. several rubberized asphalt road sections receiving everyday use are being monitored for wear and braking and skid resistance.

A technical evaluation and market study on using glass slimes in structural clay brick manufacturing has involved testing various mixes of glass in brick to act as a fluxing agent. Glass slimes are a by-product of glass recovery in resource recovery operations. They consist of very fine glass particles (less than 150 mesh) and mixed organics amounting to perhaps 20 or 30 percent of the slime by weight. The study examined the effect of adding slimes (up to 15 percent by weight) to bricks as a curing agent. The results have shown that bricks so made possess equal or superior quality to conventional bricks and that curing temperatures can be lowered by 100°F. It appears that this highly attractive approach offers three distinct advantages for handling the troublesome slimes: (1) higher quality bricks and energy savings in brick manufacture, (2) a market for glass slimes estimated at $5 to $8/ton FOB the brick plant, and (3) savings in the $5 to $12/ton disposal cost normally required to landfill the slimes.

An economic analysis has shown the feasibility of employing scrap futures markets for ferrous and waste paper. Establishment of the concept could aid the trading of these secondary materials and encourage the flow of capital to the scrap industry. A related study is examining the relationship between variable user charges for solid waste collection and management and the quantity of solid waste generated as well as the impact of charges on littering.

ENVIRONMENTAL IMPACT

Several continuing projects involve investigations of the emission and needed controls to make resource recovery systems environmentally acceptable. One study involves emissions from preprocessing and bioconversion systems. Investigators are characterizing pollutants, developing assessment criteria and pollutant measurement techniques, and performing a trade-off analysis of costs and performance of pollution control equipment. Another study will involve selection and on-site testing of various air pollution control devices, with a determination of unit acceptability and needed improvements.

In conjunction with the St. Louis bacteria-virus study discussed previously, tests were conducted and determined that fabric filters (i.e. baghouses) can significantly reduce the high levels of bacteria in the emissions from the processing plants.

Another study is investigating potential methods available for removing lead and other metals from solid waste. The presence of lead in solid waste has resulted in potentially unacceptable levels of lead in the emissions from facilities combusting RDF with coal.

In another study, the impact of resource recovery on the environment is being assessed. The study will help to quantify the reduction in environmental pollution which may result from the recovery of selected materials.

SPECIAL STUDIES

SHWRD is responding to mandates of RCRA by conducting several special studies. These studies are designed to provide status reports to the Congress on various aspects of resource recovery. Studies include assessments of selected small-scale, low-technology resource recovery methods, evaluation of the compatibility of source separation with centralized resource recovery facilities, and techniques for forecasting the quality and composition of municipal solid waste. In other special studies, research priorities for resource recovery are being assessed as are the impediments to the economical operation of resource recovery facilities. The status of glass and plastics resource recovery, and the impediments to passenger tire recycling are the subjects of other special studies. These studies are currently scheduled for completion by October 1979.

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TOXIC AND HAZARDOUS WASTE TREATMENT

Under the mandates of the Resource Conservation and Recovery Act and the Toxic Substances Control Act, the EPA is in the process of identifying hazardous and toxic materials manufactured or generated by industrial operations which, if not properly controlled, pose significant environmental and public health problems. Municipal waste disposal facilities are generally not capable of treating and managing such materials and their release in certain instances from unacceptable disposal sites has led to highly undesirable environmental contamination. Accordingly, SHWRD's research program is concerned with the identification/assessment of effective techniques for treatment and control of toxic and hazardous waste materials.

These techniques involve biological processes, incineration, and chemical/physical treatment, as well as the corresponding economic and environmental impacts of such activities. The program is designed to eliminate or reduce the hazardous nature of wastes and to protect the environment. The research program includes:

1. Techno-economic Assessments
2. Environmental Impacts
3. Treatment Technologies

TECHNO-ECONOMIC ASSESSMENT

This area involves problem assessment, identifying information and research needs, and the evaluation of new and developing processes. In an effort to understand environmental damages already caused, 32 of those pesticides most widely used in the soil were evaluated for residual toxicity, degradation mechanisms, and the persistence of any toxic by-products.

Also, a study is in progress to determine the nature and amount of industrial hazardous wastes that are currently discharged or treated in the municipal sector.

Other assessments being performed involve the relevancy and adequacy of existing and developing processing techniques for selected hazardous wastes. Processes examined include catalysis, thermal degradation, chlorinolysis, sulphonation, and microwave plasma treatment. Economic evaluations are analyzing the interrelationships between control costs and regulations for hazardous waste treatment and disposal.

ENVIRONMENTAL IMPACT

Pollution levels associated with the processing of hazardous wastes are being studied to determine the environmental impacts. One project is evaluating both toxicity of by-products and the associated health and environmental hazards of air emissions from selected hazardous waste management facilities.

A second project will assess the nature and magnitude of hazardous pollutants discharged into the environment from the barrel and drum reconditioning industry.

TREATMENT TECHNOLOGIES

To effectively process the diverse hazardous wastes generated, many treatment technologies have been evaluated.

Thermal Treatment

In an evaluation of combustion (incineration) techniques, time-temperature relationships were studied for the control and disposal of large quantities of Kepone. Under a new investigation, data are being generated on incinerator design, efficiency of various air pollution control devices, and materials handling problems to provide solutions to difficult waste streams such as PCB's and organo-metallic compounds.

Microwave plasma detoxification of hazardous materials shows considerable promise for eventual use for many organic compounds. To date, several compounds have been detoxified in the 5-7 lb/hr microwave unit (shown in Figure 11). These include PCB's, PMA, Kepone, Malathion, and a carcinogenic Navy red dye. During 1979, plans call for determining if the 5-7 lb/hr unit can be used to destroy small lots of hazardous organic chemicals collected in a region of the country. Also, a 10-30 lb/hr unit has been constructed and is being equipped for trial detoxification studies. It is anticipated that microwave treatment will prove to be an effective method for destroying small quantities of highly hazardous chemicals that otherwise pose a difficult treatment/disposal problem.

Biological/Chemical/Physical Treatment

Biological and chemical degradation techniques for controlling and detoxifying specific hazardous wastes have been investigated. In an evaluation of the treatment capabilities of biodegradation as applied to problematic hazardous wastes, four sites were investigated to evaluate design and operational data at facilities successfully treating organic industrial wastes. Treatment processes evaluated were (1) conventional air-activated sludge, (2) anaerobic-aerobic facultative lagoons, (3) deep shaft oxygen treatment, and (4) pure oxygen activated sludge. Results from the engineering, economic comparisons, and evaluation of treatments revealed that the facultative lagoon system (Figure 12) is favored over other biological methods for treatment of waste organic chemicals.

In evaluating the overall efficiency of pesticide pits, disposal and rinsing water disposal techniques, the biodestruction rates for several compounds and environmental emissions have been determined. The concrete-lined disposal pit (Figure 13) has proven, after two years of investigation, to be an effective, practical and environmentally safe method for control of dilute pesticide solutions from agricultural operations. Plans call for the initiation of a pesticide pit demonstration program in 1979, in cooperation with USDA, Soil Conservation Service.

Chemical concentration/conversion of chlorocarbons and pesticide residue into useful industrial chemicals has been evaluated as a means of control. Catalytic decomposition techniques were also investigated. Specifically, catalytic hydrogenation of chlorocarbons was successful, but some reaction products were, themselves, toxic. The role of catalysts in controlling hazardous materials has not been completely determined and additional research is likely to be required.

Encapsulation techniques have been developed for the safe storage/disposal of hazardous materials. Laboratory scale leaching studies of an encapsulated matrix are completed. Field verification studies are planned for cementitious and polymeric encapsulates.

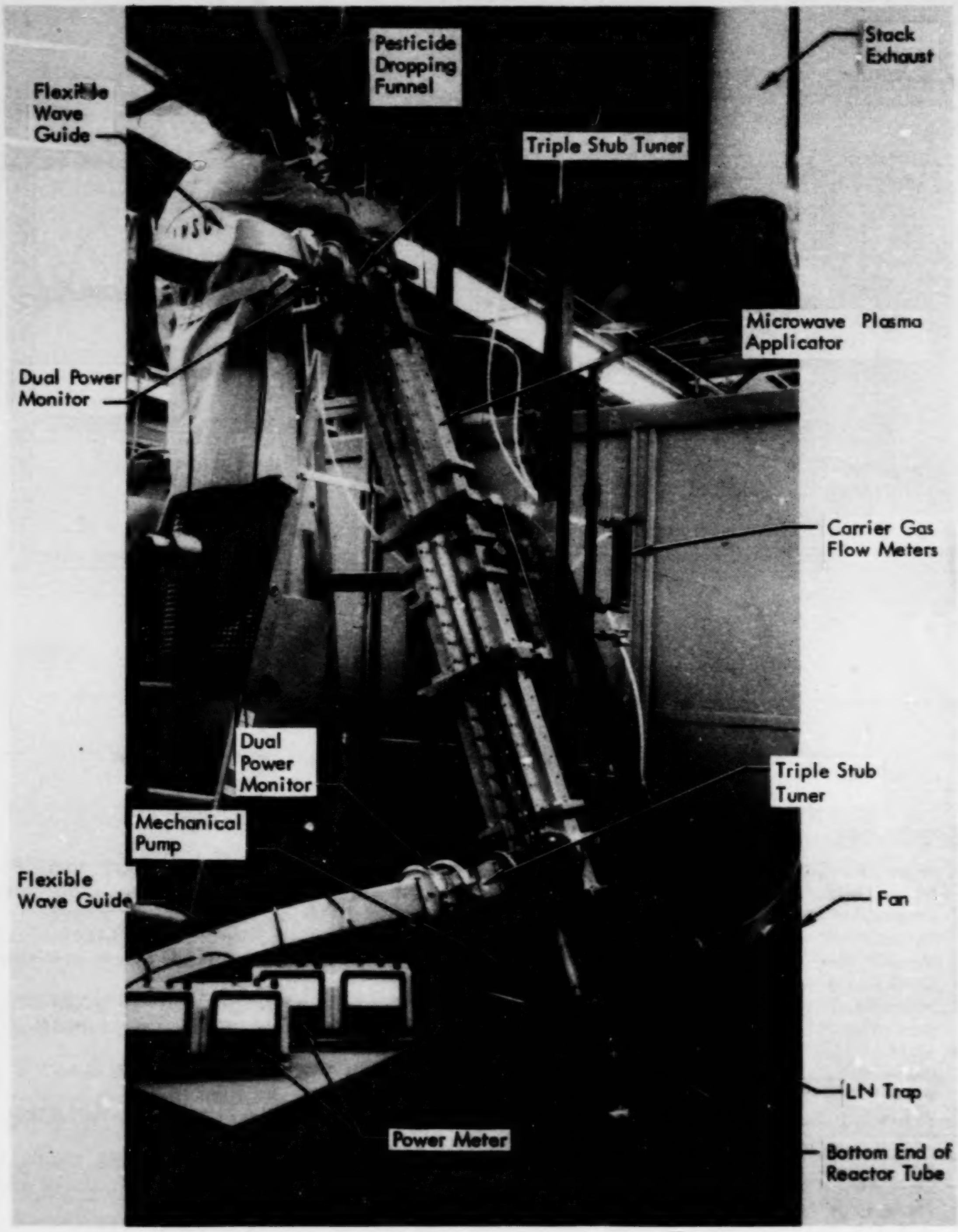
Pesticide Dropping Funnel
Stack Exhaust
Flexible Wave Guide
Triple Stub Tuner
Microwave Plasma Applicator
Dual Power Monitor
Carrier Gas Flow Meters
Dual Power Monitor
Triple Stub Tuner
Mechanical Pump
Flexible Wave Guide
Fan
LN Trap
Power Meter
Bottom End of Reactor Tube

Figure. 11. Pilot-Scale Microwave Plasma Detoxification Unit.

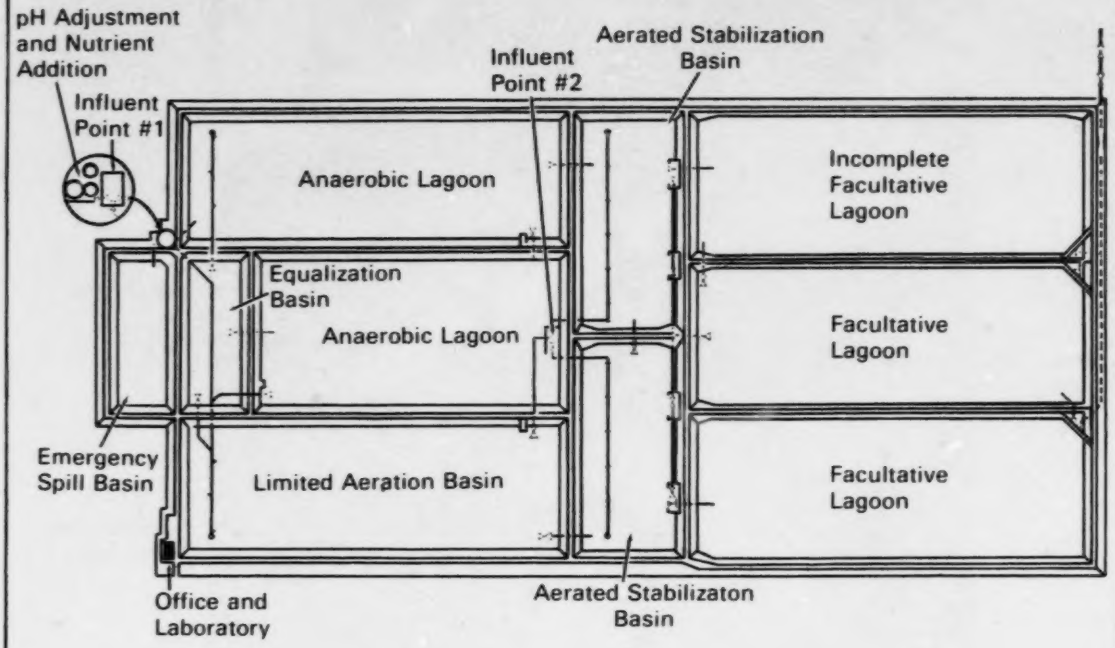
pH Adjustment and Nutrient Addition
Influent Point #1
Aerated Stabilization Basin
Influent Point #2
Anaerobic Lagoon
Incomplete Facultative Lagoon
Equalization Basin
Anaerobic Lagoon
Facultative Lagoon
Emergency Spill Basin
Limited Aeration Basin
Facultative Lagoon
Office and Laboratory
Aerated Stabilizaton Basin

Figure 12. Anaerobic-Aerobic-Facultative Treatment; Schematic Design.

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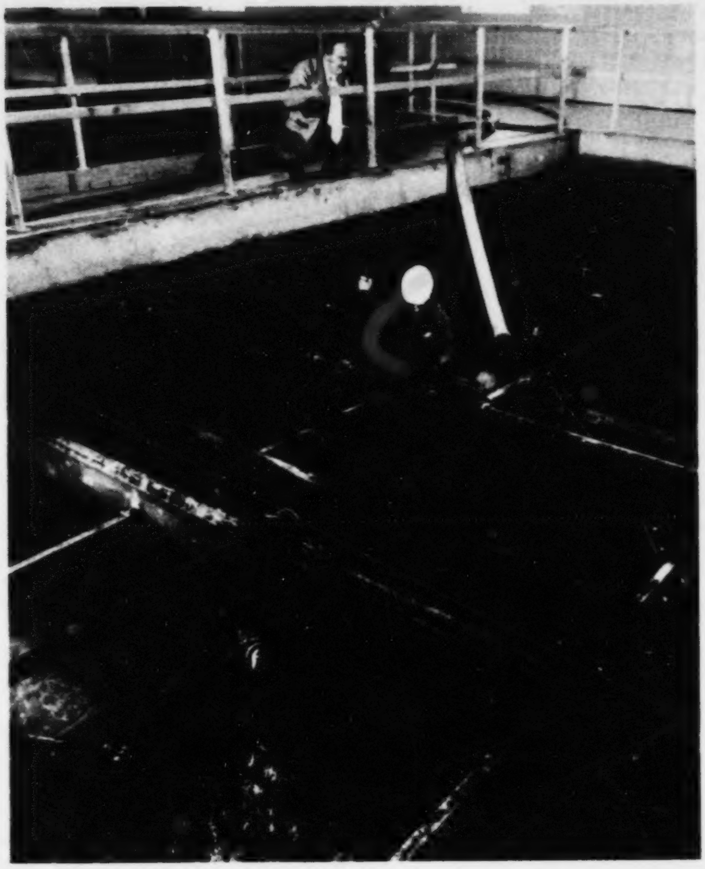

Figure 13. Pesticide Disposal Pit at Ames, Iowa.

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WASTEWATER RESEARCH DIVISION

The Wastewater Research Division (WRD) was formed in July of 1975 from the Advanced Waste Treatment Research Laboratory which had been initiated in Cincinnati in 1960. Advanced waste treatment work had been carried out under both the U.S. Public Health Service and the Department of the Interior before the establishment of the U.S. Environmental Protection Agency in 1970. With the passage of Public Law 92-500 in 1972, with changes in the national perception of municipal research problems, and with a consolidation of USEPA municipal wastewater pollution research within MERL, the range of topics expanded beyond those formerly addressed. Wastewater Research Division had become a more accurate description of the program.

The broad range of technical areas and pollution control approaches being considered by the Division is reflected in three special topics described herein. The first topic describes some recent pilot plant research in sludge dewatering, a different engineering problem with grave impact upon waste treatment plant costs. This work proves that the use of various modes of filter press operation can produce dewatered sludge suitable for incineration at quite advantageous unit costs, and with annual savings numbering millions of dollars over alternate methods. The methods described also promise to be useful in retrofitting existing equipment. The second topic discusses the operation of a promising new biological treatment method, the deep shaft process. Wastewater flow into and out of a shaft which may be hundreds of feet (or meters) deep produces high oxygen levels at the bottom and a high-intensity, high-rate treatment process, with reduced sludge production. The third topic introduces the concept of treatability of hazardous compounds, and the need for discovering what factors govern its progress. Studies on treatability can proceed on two tracks: consideration of the molecular characteristics of the compound; and observation of removal of specific compounds in bench-scale or pilot plant processes such as adsorption, biodegradation, and chemical modification.

Following the special topics is a description of the work and of important accomplishments in the Division.

SPECIAL TOPICS

Improved Dewatering Techniques For Sewage Sludges

A major factor contributing to the difficulty of disposing of sewage sludge is the tenacity of its grip on the water it contains. Sludge typically can be brought to about 95% water content by relatively inexpensive processes like thickening. To remove more water, the sludge must be treated with coagulating chemicals and vacuum filtered, centrifuged, or pressed. The commonly used dewatering devices, vacuum filters and centrifuges, can produce an 80% moisture content sludge cake from a mixture of primary and secondary sludge, still leaving four times as much water as solids in the product. This excess water greatly complicates subsequent disposal steps. Trucking costs to disposal sites are higher because of the increased amount of water that must be hauled. If the cake is discharged to a landfill, its semisolid condition makes operation unsanitary and dangerous. The landfill fills up prematurely because of the volume occupied by the water, and the excessive water load intensifies the problem of leachate contamination of groundwater from the landfill in subsequent years. If sludge is to be incinerated, a disproportionate amount of auxiliary fuel is needed - as much as 100 gallons of oil per ton of dry sludge solids.

Devices are now appearing on the market that produce a drier sludge cake - as low as 55% moisture. Most of them are so new that operating experience under a variety of conditions is inadequate. In order to help Washington, D.C., make a proper choice of dewatering equipment for their Blue Plains' plant, and to provide good comparative data for the wastewater industry, EPA's Region III and MERL funded a comparative study of a variety of dewatering devices designed to produce a low moisture sludge cake.

The one and a half year study, which began in 1976, was performed by District of Columbia staff in the EPA-DC pilot plant, using equipment available in the pilot plant as well as equipment provided by various manufacturers. The types of dewatering devices studied were:

1. Vacuum filter
2. Vacuum filter add-on devices
3. Continuous horizontal belt press
4. Recessed plate filter press operated at 100 pounds per square inch pressure
5. Recessed plate filter press operated at 225 pounds per square inch pressure
6. Recessed plate filter press with internal diaphragm for squeezing additional moisture from cake

Various combinations of primary and waste activated sludges were used in comparing performance of the dewatering devices. Conditioning agents, either ferric chloride and lime or polymeric conditioning agents, were used to enhance the filterability of all sludges. The target for all devices was to produce 65% moisture cake for a sludge with a 2:1 ratio of waste activated to primary sludge. At this moisture content, sludge cake can be incinerated with little auxiliary fuel. It has the structural strength of cardboard, no longer drips contaminated water, and offers no problems to landfill operators.

When mixtures of lime and ferric chloride were used to condition the sludge, filter presses could dewater sludges containing up to 100% activated secondary sludge to less than 70% moisture content. However, similar sludges conditioned with polymers could not be made to dewater satisfactorily in a filter press. When the coagulation effect produced by the conditioning chemicals was less than optimal, only the diaphragm filter press could consistently produce a cake of 65% moisture content. The high pressure press (225 psig) required 62.3% more filtration area than the diaphragm press to produce equivalent results; for the low pressure press (100 psig), 126.8% more area was needed.

With a 2:1 mixture of secondary and primary sludge, the standard rotary vacuum filter produced a 78-80% moisture cake. A retrofit unit that pressed the cake while it was still on the vacuum filter surface was capable of decreasing the cake moisture to only 75 percent. The high pressure section of a continuous belt press, however, decreased vacuum filter cake moisture to 65% or lower.

The continuous belt filter (Figure 14) dewatered a polymer-conditioned 2:1 mixture of secondary and primary sludge to produce a cake of less than 70% moisture. However, performance of the belt filter was not consistent, because sludge variability resulted occasionally in marginally conditioned sludges that the unit could not handle. Poor pressate quality was a problem–about 5% of the solids escaped capture. The generally good performance of the belt filter was an important finding. With a sludge of less variability than the Blue Plains' sludge, it can provide a low capital cost solution to sludge dewatering.

Economic analysis of the dewatering devices showed that on a unit cost basis, for dewatering only, the belt press ($25.64 per ton dry solids) and the vacuum filter ($40.25 per ton dry solids) provide the lowest dewatering costs. Unit costs of about $54.00 per ton dry solids are nearly the same for the three types of filter presses. Cost of incinerating filter press cake is $48.00 per ton dry solids versus $105.62 per ton dry solids for vacuum filter cake.

The study offered some interesting conclusions. First, at Blue Plains the use of filter presses versus vacuum filters to dewater sludge prior to incineration will result in annual savings of 4 to 5 million dollars in operating costs. Second, the diaphragm-type filter press offered the most flexibility and yielded the best product. Third, the continuous belt filter press holds considerable promise as a retrofit device to further dewater cake from a vacuum filter; continued development of this technology could provide considerable savings in capital expenditures. Finally, for a plant that produces a highly variable undigested sludge or one with high percentages of waste activated sludge, the filter press will provide the best operation in producing a low moisture cake, generally 65% moisture. For a plant that produces a relatively consistent stabilized sludge with a fibrous primary sludge and only small amounts of waste activated sludge, the continuous belt filter press should be thoroughly evaluated since cake moistures of 70% or less can be expected.

In general, the study showed that a cost-effective dewatering technology is emerging that is not only capable of producing low moisture sludge cake, 70% or less, but also offers plants a promising option of increasing dewatering capability by retrofitting existing equipment.

Deep Shaft Treatment Of Municipal Wastewater

The development of new wastewater treatment technology with the potential for significantly reducing life cycle costs and/or energy requirements is a long-standing Agency goal which received renewed support in the 1977 Amendments. One novel biological treatment approach which shows promise of achieving these objectives is the Deep Shaft Process. This process was developed in England by Imperial Chemical Industries (ICI) as an outgrowth of fermentation research for single cell protein production. Deep Shaft Process is now being marketed in North America by Canadian Industries Limited (CIL), a wholly-owned subsidiary of ICI.

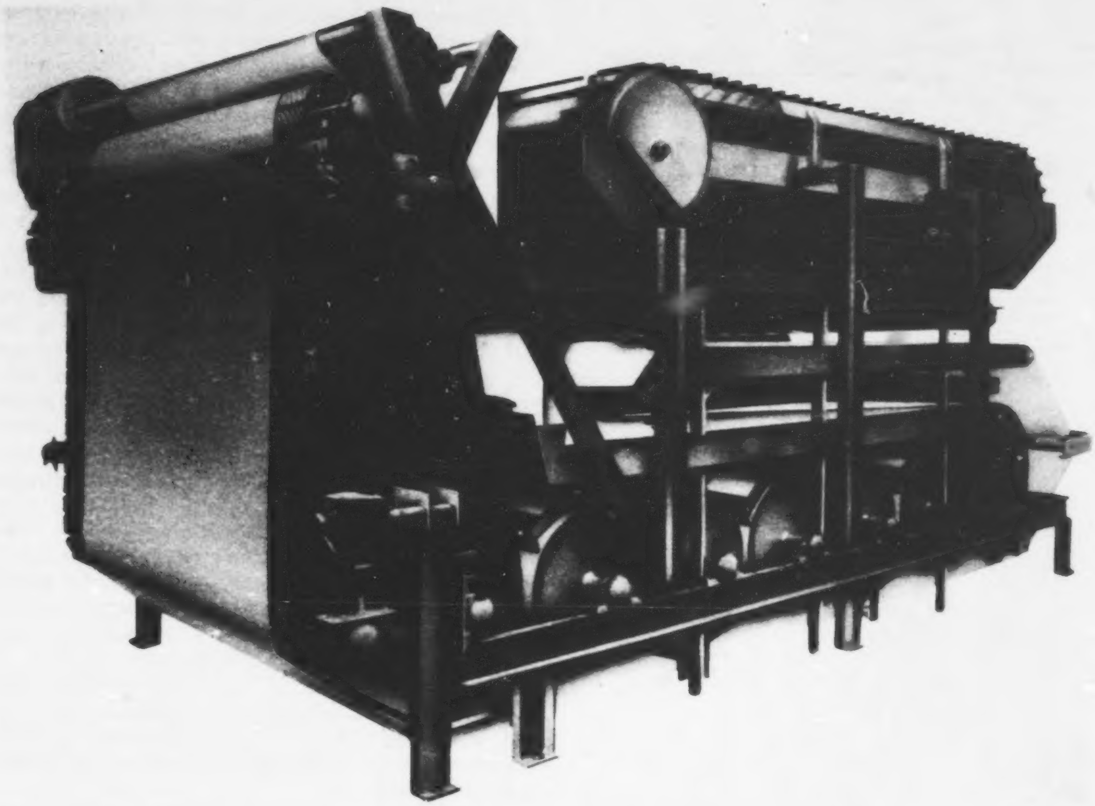


Figure 14. A "New Generation" Belt Filter, Designed to Produce Sludge Cake of High Solids Content (Unimate Belt Press, Komline-Sanderson Corporation).

The Deep Shaft Process is an underground vertical shaft with a downcomer leg and a riser leg as shown in Figure 15. Raw wastewater and return activated sludge are introduced continuously to the top of the downcomer and circulated through the shaft by the injection of compressed air. To initiate the process, compressed air is directed to the riser leg to induce circulation via simple air-lift principles. Once circulation is established, air injection is gradually transferred to the downcomer leg. Circulation is maintained due to the net difference in total bubble volume (voidage) between the riser section and the downcomer section. Since there is no voidage above the downcomer injection point (normally located at 30-40% of shaft depth), liquid in the downcomer is heavier and the greater weight forces flow down the downcomer and up the riser. The liquid velocity created is 4-7 times larger than the rise velocity of the injected air bubbles, carrying them along with the mixed liquor flow where the combination of high turbulence (Reynolds Numbers in excess of 100,000) and elevated pressure produce efficient oxygen dissolution. Functioning in this fashion with the ingredients of substrate, active biomass, and dissolved oxygen all present, the shaft becomes a vertical activated sludge bioreactor.

Shaft size can be tailored to meet varying hydraulic and organic loading conditions. Shaft depths from 150-1000 ft (45-300 m) are possible while shaft diameters can vary from 18 in to 18 ft (0.5-5.0 m). Depending on geologic conditions and shaft dimensions, conventional drilling or mining techniques are employed to construct the shaft. The mining option is normally reserved for large diameter jobs. When the shaft is drilled, it is lined with prefabricated steel and grouted with sulfate resistent cement. The downcomer typically consists of a smaller concentric pipe in drilled shafts. For mined shafts, concrete will usually be specified for the lining with a concrete partition dividing the shaft into downcomer and riser legs.

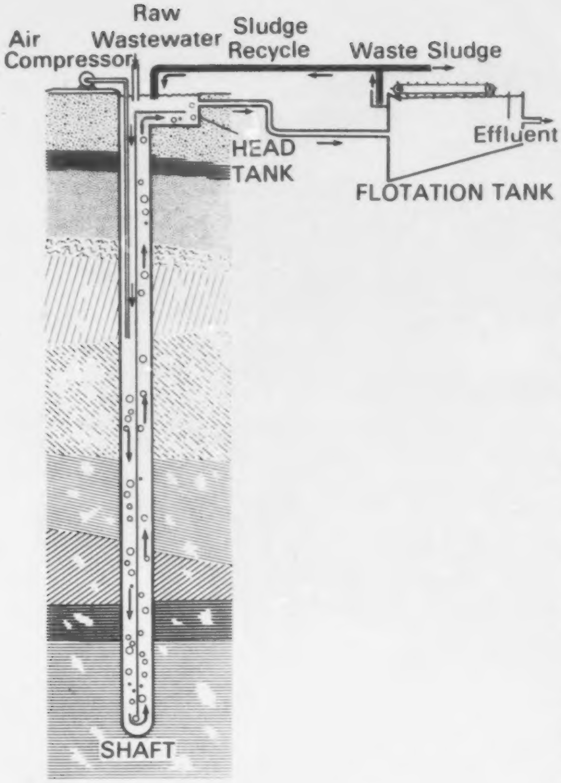


Figure 15. Deep Shaft Schematic Diagram.

The increased pressures associated with increased depths produce a dissolved oxygen profile which varies from near zero at the top of the downcomer to 40 mg/l or more at the bottom. As the mixed liquor travels up the riser, pressure decreases and dissolved nitrogen, carbon dioxide, and residual oxygen come out of solution forming gas bubbles which are released to the atmosphere in a disengagement head tank surmounted on the shaft.

The hydraulic mixing regime established in the shaft results in a high–intensity, high-rate process. Nominal overall detention time for most municipal operations will range from 40-80 minutes depending primarily on the mixed liquor suspended solids (MLSS) concentration employed. The high internal circulation rate built into the design produces a 10-50 – fold dilution of the influent wastewater and residence times per pass of only several minutes. Thus, although substrate removal is patterned after plug flow kinetics during each pass, the net effect of the rapid circulation pattern is the operational stability associated with complete mix activated sludge.

Liquid/solid separation can be accomplished in two ways. The first utilizes a vacuum degasser to further effervesce dissolved gases not removed in the disengagement head tank. A conventional gravity clarifier follows the degasser. MLSS levels in this mode are generally restricted to 5,000 mg/l or less because of the solids loading (flux) limitations of settling tanks. Settled sludge typically thickens to about 10,000 mg/l, resulting in a approximate 100% sludge recycle rate.

The second method takes advantage of the natural tendency of the mixed liquor leaving the riser to float. Instead of undergoing degassing, the mixed liquor is transferred directly from the head tank to a flotation tank for final liquid/solid separation. Pilot plant experience in Canada indicates that, with appropriate polymer addition, the subnatant routinely meets secondary treatment standards and is suitable for discharge without add-on polishing steps. Solids concentrations in the float vary from 5-10%, thus obviating the need in most cases for separate thickening of waste sludge. Without the solids loading constraints which influence gravity clarifier operation, MLSS in the flotation mode are held around 10,000 mg/l, thereby requiring a sludge recycle rate of only 25% or less. The bioreactor nominal detention time can thus be halved while still maintaining the same food-to-microorganism (F/M) loadings as in the gravity clarifier mode.

Pilot plant operating and performance data have been generated at Billingham, England, on municipal wastewater (96,000 gpd) (363 m^3/day) and at Paris, Ontario, on a combined municipal-textile influent stream (120,000 gpd) (454 m^3/day). Effluent BOD and suspended solids concentrations of 15-20 and 20-25 mg/l, respectively, were observed at volumetric organic loading rates of 200-260 lb BOD/day/1000 cu ft (3.2-4.2 kg BOD/day/m^3) of shaft volume. The Deep Shaft Process is being evaluated in Canada, the United Kingdom, continental Europe, Japan, and the United States on a variety of industrial applications including the treatment of brewery, dairy, food processing, potato starch, textile, and chemical waste streams. The first full-scale (30 in x 500 ft) (0.8 m x 152 m) municipal installation is under construction at Virden, Manitoba. It will have a capacity of 0.6 mgd (2,270 m^3/day). No Deep Shaft municipal construction has yet been initiated or approved in this country.

To expedite consideration of this novel technology in the United States, a demonstration grant was awarded to the City of Ithaca, New York, in August, 1978. The City will construct and operate an 18 in. x 435 ft (0.5 m x 133 m) facility on the grounds of its existing wastewater treatment plant as part of its facilities planning investigations for expansion. Ithaca's treatment plant borders green belt areas and the city would like to find a suitable plant expansion method which maximizes land conservation, one of the principal features of Deep Shaft. The 30-month project will include 18 months of system operation and data collection. Total project costs will exceed $750,000 with an EPA contribution of $500,000.

A dual-purpose clarification unit will be fabricated which will enable evaluation of both the flotation and sedimentation modes. Design flows in these two modes will be 200,000 and 100,000 gpd (757 and 379 m^3/day), respectively, corresponding to nominal detention times of 38 and 76 minutes. The F/M loading in both modes is projected to average approximately 0.75 kg BOD/day/kg MLVSS under aeration. Volumetric organic loadings will approximate 350 and 175 lb BOD/day/1000 cu ft (5.6 and 2.8 kg BOD/day/m^3) in the flotation and sedimentation modes, respectively. System start-up following shaft installation is expected sometime in March 1979. Preliminary performance results should be available in 10-12 months after that with final data accumulation completed in the fall of 1980.

Parameters to be evaluated, in addition to process performance, will include power consumption, excess sludge production, and the economic tradeoff between the larger reactor volume required in the gravity clarifier mode versus polymer requirements in the flotation mode. Power consumption is tied directly to oxygen uptake rate and oxygen utilization. Due to the combination of high intensity mixing and greatly elevated pressures, oxygen transfer rates up to 180 lb/1000 cu ft/hr (2,885 kg/m^3/hr) and oxygen utilizations of 90 percent or more are reportedly achieved, yielding an effective power transfer rate in wastewater of 4-6 lb O_2/hp-hr (2.4-3.6 kg O_2/kWh). By comparision, conventional air aeration systems typically achieve 5-15% oxygen utilization and 1-2 lb O_2/hp-hr (0.6-1.2 kg O_2/kWh) power transfer rate. The potential economic savings in energy are considerable if the above figures for Deep Shaft power consumption can be verified.

The unusual cycling environment created by rapid circulation in the shaft is also credited with stimulating high microorganism respiration rates at the expense of cell synthesis. This phenomenon has led to claims of potential reductions in excess biological sludge production compared to conventional activated sludge regimes. Based on pilot plant experiences to date, it is anticipated full-scale excess sludge production will approximate 0.5 kg TSS/kg BOD removed at F/M loadings of 0.75-1.0 kg BOD/day/kg MLVSS. Historically, sludge production at loading rates of this magnitude would be expected to approach 1.0 kg TSS/kg BOD removed. Because of the huge capital and operating costs involved in sludge processing and disposal, this aspect of Deep Shaft operation also suggests significant potential economic savings.

Treatability Of Hazardous Compounds

Treatability

It is an inescapable truism that rapid progress in the control of toxics cannot be made unless the knowledge is obtained on how a compound behaves in the evnironment or in a particular unit process of a treatment system. The task is enormous because of the great number and variety of compounds and the great diversity of conditions in an environment or process, but it must be done. The task can be reduced to manageable proportions if methods are developed to predict behavior rather than resorting to experimental investigation of each compound under each environmental condition.

Research on how a compound behaves in a particular environment can take two general routes. One approach, which can be described as *treatability*, makes the assumption that a compound will behave in a predictable manner that is characteristic of the compound, as much as solubility and vapor pressure, etc., are specific for the compound. Thus, the research considers pure compounds and progresses from pure solutions to the more complex solutions represented by wastewaters and sludges. With enough basic information on the behavior of the compound and its molecular characteristics, it may be possible to develop models which predict the behavior of other untested compounds. In the investigations of treatability, a variety of processes must be addressed such as: adsorption (soils, solids and carbon), biodegradability (aerobic and anaerobic) volatility and chemical modification (by oxidation, precipitation, etc.).

Another approach to this kind of research is to observe removals of compounds across various unit processes such as sedimentation, biological oxidation, carbon contactors, etc. Much can be learned from this approach about the unit process but since many mechanisms operate in most processes, little fundamental knowledge will be gained about the compound itself. This research can be characterized as *removability*.

Because of the need for both short and long term information, research is taking both approaches of *treatability* and *removability*.

Adsorption On Activated Carbon

One of the potentially useful processes for control of toxic organic compounds is adsorption on activated carbon. It has the merit that the compounds are destroyed when the carbon is thermally regenerated.

Since adsorption is basically a surface phenomenon, it follows that substances with very high surface areas are desirable. Carbon is unique in that it possesses a very high surface area to mass ratio. Surface areas of carbons range from ~ 600 m^2/g to > 2000 m^2/g. Most of the surface area (95%) is contained in internal surfaces of pores and capillaries that are developed during activation of the carbon. An electron microscopic view of a carbon granule, shown in Figure 16 (provided by Dr. W. J. Weber of the University of Michigan) shows a rough exterior surface which is pockmarked by *holes* which constitute most of the surface area.

Adsorption is a complex process which involves both the nature of the carbon surface as well as the characteristic of the molecule. Some of the latter factors include solubility, molecular weight, polarity, ionization, orientation at the surface, and more. All of these factors contribute to the adsorbability of a compound which, operationally, can be determined quantitatively by determining a batch equilibrium adsorption isotherm, which mathematically can be described by the equation:

$$\frac{X}{M} = KC_f^{1/n}$$

where:

$\frac{X}{M}$ = the "loading" of the compound on the carbon in mg/g of carbon

C_f = the amount of compound remaining in solution after carbon treatment

K and 1/n are empirical constants.

The data, when plotted on log-log paper generally produces linear curves, from which much information can be inferred by observing the intercept, K, and the slope 1/n. Some typical isotherms are illustrated in Figure 17. It can be seen that adsorption of benzene, because of the steep slope of the isotherm, shows rapidly declining adsorption capacity on carbon and low residual concentrations would be difficult to achieve. The adsorption isotherms for β-naphthol and benzidine are more favorable for adsorption with the former being adsorbed at higher loadings on carbon. These isotherms were taken from a list of some 60 compounds that were collected into a single publication entitled *Carbon Adsorption Isotherms for Toxic Organics*, Municipal Environmental Research Laboratory, Cincinnati, Ohio 45268, May 1978.

While carbon is highly effective for the removal of organics, it is important to point out that the variation of loading on carbon is great. For example, the adsorption of 60 compounds mentioned above varied over 0-360 mg/g of carbon at an initial concentration of 1 mg/l of

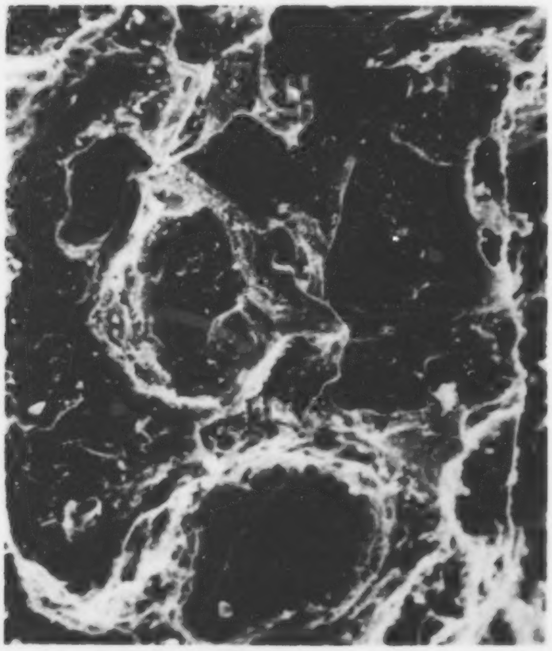


Figure 16. Electron Microphotograph of a Carbon Granule.

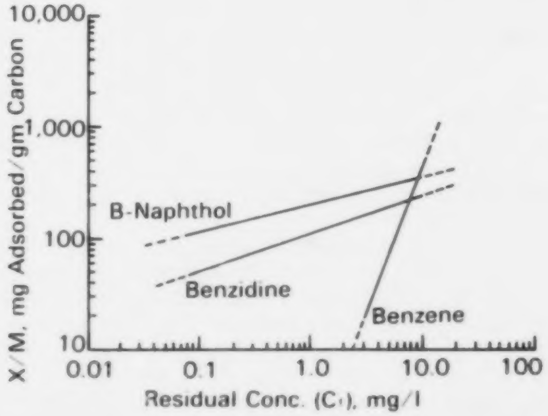
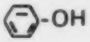
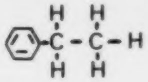
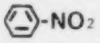
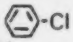
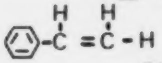
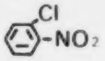


Figure 17. Carbon Adsorption Isotherms for Selected Compounds.

compound. Relatively small changes in a molecule can alter the adsorbability of the compound. This change in adsorbability is illustrated in Figure 18 which shows the marked effects of substitutions on a benzene molecule. All adsorption capacities are given at an initial concentration of compound of 1 mg/l. Thus, unsubstituted benzene is barely adsorbable, 0.7 mg/g. Substituting an OH group for one of the H in the benzene molecule increases the adsorption by a factor of 30. When Cl is substituted, this factor increases to 133.

In summary, adsorption (or non-adsorption) depends on many factors, not the least of which is the substitution on a parent molecule. It is one of the goals of the research on treatability to discover those factors which govern adsorption and ultimately to be able to predict adsorption in some systematic way. Without this capability, laboratories will be burdened with the need to evaluate adsorption for thousands of compounds.

Compound	Structure	Adsorption Capacity *(mg/g)
Benzene		0.7
Phenol		21
Ethylbenzene		53
Nitrobenzene		68
Chlorobenzene		93
Styrene		120
1-Chloro-2-Nitrobenzene		130

*Measured at 1 mg/l initial concentration

Figure 18. Adsorption Capacities for Benezene and Substituted Benezenes.

TECHNOLOGY DEVELOPMENT SUPPORT BRANCH

OBJECTIVES AND ACCOMPLISHMENTS

The Technology Development Support Branch provides technical and support services to the Division. It operates and maintains pilot plants and provides analytical services to all Division technology development operations. It is composed of the Pilot and Field Evaluation Section and the Waste Identification and Analysis Section.

Pilot and Field Evaluation Section

The Pilot and Field Evaluation Section is responsible for conducting most of the WRD pilot plant studies. These are conducted with U.S. EPA personnel at the Lebanon Pilot Plant and under contract with the Los Angeles County Sanitation Districts, Los Angeles County, California. In addition, personnel of this Section manage the national program in Instrumentation and Automation for Wastewater Treatment Systems. Some of the instrumentation and automation work is conducted at the pilot plant facilities mentioned above, but most is implemented through contracts and grants.

During this year a major activity was construction of the new Test and Evaluation Facility (Figure 19) on the grounds of the Mill Creek Sewage Treatment Plant in Cincinnati, Ohio. This 30,000 square foot facility will be the site of the major MERL pilot plant activity for many years in the future. The facility is equipped with all of the services required for research on water pollution control. Raw sewage, primary effluent, secondary effluent, primary sludge, secondary sludge, digested sludge and heat treatment liquor will be available on a continuous real time basis at any of 14 stations in the facility. In addition, access on a controlled basis to the industrial waste tank farm at this plant has been procured. This will make it possible to conduct studies on treatment of specific industrial wastes and on mixtures of industrial wastes and municipal wastes. The facility is equipped with a machine shop, dry chemical storage, wet chemical storage, two wet laboratories, an instrument laboratory, two cranes, office space, pure oxygen supply, compressed air supply, 110V, 220V, and 440V electric power. As much as possible, instrumentation will be used to monitor the processes under study. A computer system will be installed to log data, manipulate data, plot results, generate reports and implement process control.

Construction on this facility began in October 1977 and will be complete in January 1979 The facility should be operating at near full capacity by July 1979.

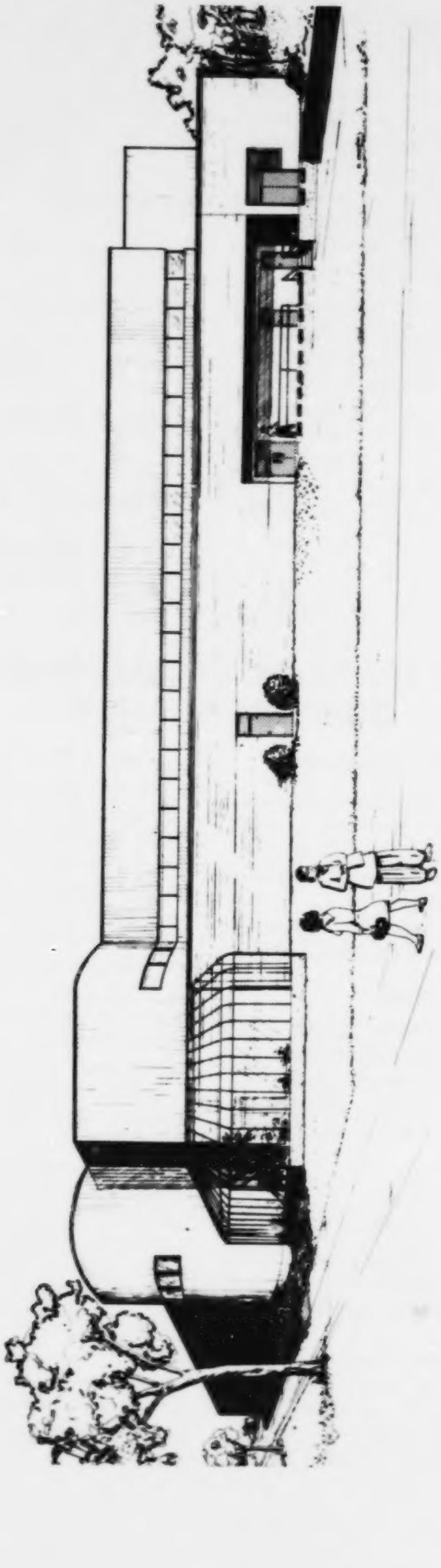


Figure 19. The New Test and Evaluation Facility.

The Lebanon pilot plant is scheduled for shutdown by January 1979. Thus, during the last year studies underway at this facility have been brought to a conclusion. One of these studies was an evaluation of the feasibility of joint treatment of septage and sludges generated at biological treatment plants. Long-term daily feed studies of anaerobic digestion of mixtures of septages and conventional sludge were conducted. Detention times ranging from 10 to 30 days were used with mixtures ranging from 0% septage to 100% septage. It was found that the presence of septage had no effect on the performance of the anaerobic digestion systems. Thus, it is feasible to treat septage by anaerobic digestion along with conventional sludge. Companion studies of treatment of mixtures of septage and conventional sludge with aerobic digestion are still being conducted. The septage has not interferred with the biological stabilization of the septage and sludge. However, intense foaming often takes place in the units fed septage. If the air supply is reduced to control foaming, the system becomes anaerobic and results in decreased degradation of organics.

Among the other studies underway at Lebanon are the effect of activated carbon on anaerobic digestion, the effect of nitrate on activated carbon performance, and attempts to verify and then use mathematical models of anaerobic digestion to control that process.

At the Joint Water Pollution Control Plant in Los Angeles County, two major studies are underway or were completed. A study of a sludge stabilization system employing heat treatment and anaerobic digestion indicated that heat treatment slightly increases the quantity of methane which can be produced during anaerobic digestion. However, anaerobic digestion after heat treatment negates a portion of the increase in sludge dewaterability resulting from heat treatment. The liquor from heat treatment could be easily treated in an anaerobic contact filter.

Successful composting of digested sludge dewatered in a solid bowl centrifuge by the open-air window method was previously achieved at this plant. However, when the cake from a second stage basket centrifuge was added, composting was poor because the second stage cake has a higher moisture content. Various attempts to overcome this including the use of bulking agents, artificial aeration, etc., were not successful. The study will continue in an attempt to resolve the problem.

Instrumentation and Automation Program

A major activity of the Instrumentation and Automation program was the demonstration of automated analysis and control of the solids handling processes. As a part of this program, a control strategy is now being developed for the vacuum filter (Figure 20). This strategy encompasses automatic control of the following parameters.

- ferric chloride feed flow control
- lime feed flow control
- drum speed control
- vat level control

The tests conducted to date have all been short term tests designed to assess the control characteristics of the process. However, these preliminary tests have indicated that a 40% reduction in lime dose from the dose of the previously used manual control system may be achieved.

Also, automation of sludge thickening was implemented as a part of this program. It was found that the improved control of sludge blanket level, obtained with the automatic control strategy, substantially reduced the mass of suspended solids returned to the primary sedimentation tanks. When compared to the current manual control system, the treatment cost savings obtained from the increased solids capture efficiency were found to be substantial.

A design handbook for the automation of activated sludge treatment plants is being developed for the use of sanitary engineers. Included in the handbook will be a primer on automatic control techniques, and a state of the art report on automated control strategies now in use at nine activated sludge treatment plants. The handbook will supply full documentation of the instrumentation used in implementing each of the control strategies studied. This documentation will contain the following information:

- equipment specifications
- equipment maintenance requirements
- system reliability
- system cost effectiveness

The handbook is intended to provide the sanitary engineer with guidelines for designing, procuring, and implementing automated control strategies in an activated sludge wastewater treatment plant.

An evaluation of control strategy and management information system performance will be undertaken at the Central Contra Costa Advanced Water Reclamation Plant. The new facility includes lime coagulation of raw sewage, single stage biological nitrification and sludge incineration with lime recovery. Automation will be implemented by direct digital control. Automated control strategies will be evaluated by comparing their performance and costs to the performance and costs of manual plant operation. Using the digital computer, a plant management

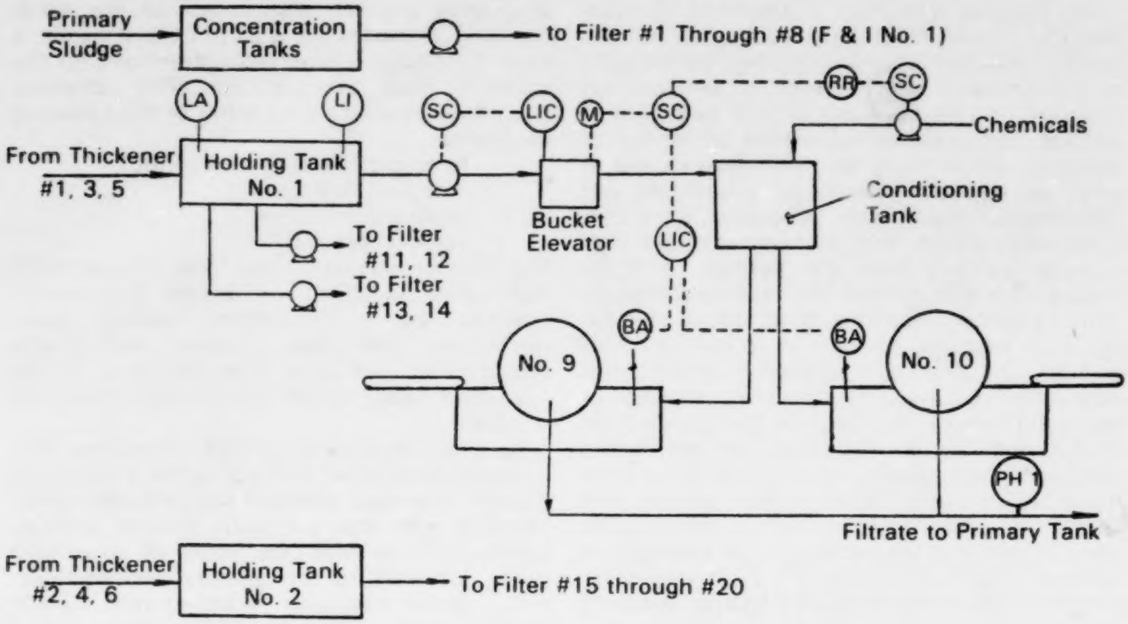


Figure 20. Schematic of Vacuum Filtration Control System.

information system will be implemented which will include such information as operational data logging, regulatory agency report generation, maintenance repair information in preventative maintenance scheduling, cost analysis, etc. The utility of the management information system will also be determined.

The U.S. EPA and the National Bureau of Standards entered into a cooperative venture to develop specifications for wastewater treatment plant process instrumentation. The specifications will include acceptance standards, installation standards, and standard calibration methods.

A separate study is being conducted to determine the feasibility of establishing an independent instrumentation test laboratory. The SIRA laboratory in the U.K. has offered their assistance and may be used as a model for the U.S. laboratory.

Waste Identification and Analysis Section

Analytical Support

An important duty of this section is to provide accurate analyses of a wide variety of pollutants for all of WRD. Modern computerized equipment is used to handle a large sample load. Analyses include heavy metals, algal nutrients, total and suspended solids and gross organics in wastewaters and sludges. This analytical service also included extensive metals analyses for the Technical Support Division of Water and Hazardous Materials Office in their 1,000-city national water survey.

The Section also provides analytical procedures development as required to support the analytical needs of WRD. With the recent concern for the presence of toxic substances, especially organics in the wastewaters and sludges, the Section in the past year began to expand its capabilities to supply analyses of municipal wastewaters and sludges for specific toxic organics using GC, GC/MS, and liquid chromatographic techniques. Procedures for the analyses of the EPA *Consent Decree* toxic organics in municipal sludges did not exist and the state-of-the-art EPA EMSL Guidelines for these analyses in municipal raw wastewater required verification. These deficiencies in analytical capabilities created both a WRD and a national need on analytical development for analyses of toxic organics in municipal wastewaters and sludges.

To meet this need, the Section provided the lead role in a most urgent intramural-extramural project, i.e., the development of analytical procedures for priority organics in municipal raw wastewaters and sludges. These procedures were needed not only by WRD but by the EPA Office of Water Planning and Standards so that they could initiate a national survey of municipal wastewaters and sludges for the toxic priority pollutants.

A preliminary evaluation of the EPA EMSL Guidelines, *Sampling and Analysis Procedures for Screening of Industrial Effluents for Priority Pollutants,* as applied to municipal raw wastewater, was performed by the intramural teams of WRD and the Athens Laboratory, with support from Cincinnati EMSL. These guidelines featured a procedure for purgeable organics, a procedure for pesticides and PCB's and a procedure for base/neutral and acid extractable organics. Additional work on the evaluation of the EMSL Guidelines was performed by WRD and A.D. Little, Inc. Two, prototype, transportable, automatic composite samplers (previously developed by WRD) were also constructed for field evaluation on raw municipal wastewater for obtaining purgeable organics samples. These evaluations confirmed the general applicability of the EMSL guidelines for analyses of municipal raw wastewaters for priority (EPA *Consent Decree)* organics.

Development of Procedures for Municipal Sludges

The development of analytical procedures for determination of organics in municipal sludges was performed using sludges typically respresentative of those available at conventional wastewater treatment plants. These sludge samples were: thickened, combined, raw, primary-secondary sludge, and the discharge of anaerobically digested sludge from the digestor. The sludges chosen usually contained about 5% solids by weight. A modest amount of work was also performed using waste activated sludge and primary sludge separately.

The overall technical approach for analyses of municipal sludges evolved into two basic alternatives. The first alternative paralleled and modified the approach used in the EMSL guidelines for analysis of industrial wastewaters. The second sludge approach employed extractive steam distillation as a substitute for the liquid/liquid extraction of the base/neutral and acid extractable organics in the first alternative.

These approaches used extensive clean-up procedures including gel permeation chromatography and/or silica gel chromatography to prepare the extracted organics for GC/MS analyses. They also featured the use of methylene chloride or methylene chloride/methanol solvent systems in the clean-up procedures. These solvent systems provided low boiling evaporation steps to minimize losses of the organics during evaporative solute concentration before the GC/MS identification and quantitation.

The overall project has produced preliminary procedures which are being further evaluated by the intramural-extramural team. They will serve as a bases for developing an EMSL *Guideline for the Analyses of Priority Organics in Municipal Sludges.* The EMSL Guidelines are scheduled for delivery by October 31, 1978, although additional verification work will continue through December 1978.

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SYSTEMS AND ENGINEERING EVALUATION BRANCH

Objectives and Accomplishments

The Systems and Engineering Evaluation Branch is composed of the Urban Systems Management Section, the Storm and Combined Sewer Section, and the Systems and Economic Analysis Section. Its programs include the study of methods for improving the operation of publicly owned treatment works and for developing approaches to controlling urban wet weather discharges. The Branch is also responsible for providing design methods for rural, institutional and individual home systems and for conducting a program for water conservation and wastewater reuse.

Urban Systems Management Section

Operation and Maintenance

The operation and maintenance (O&M) program has experienced an expansion of program scope and diversity during 1978. Significant progress has been made relative to the program's mission of development and demonstration of methods, processes and procedures for improved operation and maintenance, effluent performance, and reliability of municipal wastewater treatment plants.

The most significant result of the O&M program has been the completion of the second phase of the National O&M Cause and Effect Survey. This survey has provided State and Federal Government policy makers and researchers with the comprehensive data base necessary to formulate and implement effective municipal treatment works corrective O&M programs. Highlights of the survey include the demonstrated cost effectiveness and success in the application of a Composite Correction Program (CCP) to improve plant performance. This program recognizes the many factors that normally cause poor performance at a given facility and that an effective corrective program must address all of them. The study showed that application of this on-site corrective program could bring over 70% of non-complying plants into compliance at a fraction of the cost necessary for alternative upgrading approaches. Because of the success of the above approach, the O&M program is progressing towards implementing the CCP on a region-wide or state-wide basis in an effort to further document and project the cost/benefits of CCP nationally.

The top ten causative factors determined from the national survey can be broken down and broadly classified as operator training and facility design problems. From the assessment of the operator training problems, the O&M program will fund a project, in conjunction with other EPA training groups, to evaluate the effectiveness of on—site operator training programs. This project will deal with developing methodologies for evaluating effectiveness of operator training programs and define the cost/benefits of on-site training programs.

Design related causative factors will also be emphasized by the O&M program over the next two years. Many of the design deficiencies determined from the survey and other sources will be summarized on a design deficiency checklist to be developed by the USMS O&M staff for immediate use by the Regional Construction Grants staff. This matrix will also be used to establish priorities in a project to develop low-cost corrections to the design deficiencies listed.

A specific high priority design program related to secondary clarifiers was identified in the National Survey. In response, the O&M program has implemented a group of separate projects which will evaluate and document improvements to secondary clarifier performance through demonstrated improvements in hydraulic efficiencies. All major types of secondary clarifiers will be evaluated through use of fluorometric dye tracer techniques. These fluorometric techniques will be used to quantify the hydraulic characteristics of full scale secondary clarifiers and propose modifications to improve these hydraulic characteristics. After modification, clarifier hydraulic characteristics will be flurometrically measured and the impact on effluent quality determined. The final output from this program will be definitive clarifier design guidelines which will emphasize the optimization of clarifier hydraulics.

The wide diversity of the O&M program can also be seen in some of its major accomplishments during 1978. In response to the O&M program's desire to evaluate processes with high levels of performance and reliability, a project was completed which examined the performance, reliability, and total cost aspects of oxidation ditch plants along with competing biological processes. The final report from this project provided basic design information for oxidation ditch plants including anticipated effluent performance and reliability. Typical O&M costs and problems were presented along with the processes' potential for nitrification and nitrogen removal. All of the information was compared to other competing conventional biological processes. The report found the oxidation ditch process to have a higher level of performance and reliability at a lower cost than other competing biological processes in the 1-10 MGD range. The final report has generated substantial interest requiring a second printing. A newsletter synopsizing the results is also in preparation which will be widely distributed to the engineering community.

A report was also completed which investigated novel methods and materials of construction for wastewater treatment plants. The emphasis of the report was to determine if the construction cost of municipal treatment plants could be reduced through introduction and use of novel methods and materials of construction. These included nonstructural factors (administrative procedures, regulatory and technical policies, constraints, etc.) as well as structural factors (construction practices, methods, and materials). Based upon potential for capital and construction cost savings and implementation feasibility, 16 nonstructural solutions were proposed and rated. For unconventional methods and materials of construction, nine potentially cost effective concepts were identified: in situ pipe liners, trenchless sewer pipe installation, sewer-within-sewers, greater use of fiberglass reinforced plastic (FRP) products including piping, bridges, plastic hydraulic control equipment, miscellaneous digester covers, covers and enclosures, and miscellaneous items. Concepts identified as novel and feasible from the standpoint of engineering, advantages and cost savings were shipboard treatment, drilled vertical shaft construction, reinforced earth tanks, precast concrete tanks and reinforced asphalt pond liners.

The O&M program's four-project reliability, engineering and analysis program is progressing toward its goal of developing overall plant reliability design guidelines. Analysis of the reliability of biological processes has continued at the University of California/Davis. Analysis of performance data from 37 activated sludge plants has resulted in a reliability model which can accurately predict the level of performance for which an activated sludge plant must be designed to meet a specific level of reliability. A similar model is in preparation for attached growth systems. Basic research is continuing on the development of a new biological stability/reliability model. It is anticipated that the final model from this project will be capable of predicting the performance and reliability of biological processes from various design, operational and environmental factors including the impact of toxic materials.

Other phases of the reliability, engineering and analysis program have continued during 1978. A contract has been negotiated with Southwest Research Institute to evaluate and document the reliability of conventional treatment plant components. This project will collect and analyze failure rate data for various generic type/application groupings of mechanical components. This information will be used in conjunction with the other reliability projects outputs in the development of overall plant reliability design guidelines. These guidelines will present data and methodology which will give design engineers the ability to design treatment processes for specific levels of reliability and perform cost/reliability analyses for various processes.

The O&M program is continuing its work in the optimization of operation and maintenance of treatment plants. Centralized management of the operation and maintenance of groups of small treatment plants represents a substantial potential O&M cost savings. A simulation model being developed with in-house staff capabilities will predict costs associated with several management alternatives for O&M of a group of plants. These alternatives would range from independent operation to circuit rider operation assisted by low-level monitoring and telemetry. Data for development and refinement of the simulation model is being collected under separate grants with Gulf Coast Waste Disposal Authority in Houston, Texas and Cuyahoga County Sanitary Engineering Department in Cleveland, Ohio. Completion of the centralized management program will include a regional demonstration of the least cost management alternatives as determined by the simulation model.

The O&M computerized data base initiated in support of the National O&M Cause and Effect Survey and other O&M initiatives will be operational in 1978. The data base will provide in-house capabilities for the analysis of a wide variety of design, operational, and geographical factors and how they impact plant O&M cost, performance and reliability. With all the programs operational, the computerized data base will allow ORD, Headquarters, and Regional people broad access to a reliable data base to answer a wide variety of questions relative to O&M costs, design, and performance capabilities of wastewater treatment systems.

Municipal Wastewater Reuse

The objectives of the reuse program are the implementation of research that proves the feasibility of: (1) the near term, less controversial, nonpotable use of wastewater to extend valuable water supplies by source substitution; and (2) the longer term, or possible emergency use of wastewater for potable purposes. The Wastewater Research Division is supporting projects in both of these areas and is coordinating its activities through a cooperative agreement with the American Water Works Research Foundation (AWWARF) and with other concerned Federal, state, and municipal organizations engaged in similar research. Periodic newsletters and reuse reports are prepared by AWWARF and distributed among participating organizations as a means of information exchange.

To assist implementation of wastewater reuse for nonpotable purposes, a wastewater reuse guidance manual is being developed. This manual is directed toward water managers and resource planners and is intended to make the user aware of proven reuse possibilities that may exist nearby, and to alert the user to EPA's support and encouragement for the reuse approach. Following the step-by-step plan provided in the manual, the water manager and resource planner will be able to address the principal areas of concern encountered in developing sound water reuse programs, including technical constraints, water quality criteria, economics and financing, legal issues and institutional arrangements, long-term program dependability, marketing the resource, public information, and steps toward implementation.

Because the quantity and quality of municipal wastewater can be affected by water conservation programs implemented by water utilities, data collected from wastewater treatment facilities operating during the 1976 and 1977 drought conditions in the western United States, when water conservation was instituted as the most efficient means of reducing water demand, are being analyzed to determine the impacts on sewers and the ability of treatment plants to meet discharge and reuse quality requirements with more concentrated influents. Because of these concerns, data are needed to make recommendations for a policy and follow-on action if water conservation is to be advocated on a continuing basis.

Recognizing the potential benefits of the planned reuse of wastewater for domestic purposes, and recognizing health questions associated with the already existing unplanned reuse of wastewaters such as occurs in communities throughout the U.S. which have water intakes downstream of waste discharges, the U.S. Congress included in Section 1444(a)(2) of PL 93-523, the *Safe Drinking Water Act,* authorization to establish a program to demonstrate the reuse of wastewater for drinking purposes. In addition, Section 5 of PL 95-155, the EPA Research and Development Authorization Act of 1978, re-emphasizes Congress's interest in establishing a potable reuse demonstration program. The initiation of this program is a major new responsibility of the Wastewater Research Division.

Data is being collected on the extent of unplanned reuse for potable purposes in a project to determine the percentage of wastewater in water supplies of U.S. cities with a population of 25,000 or more. Five hundred and eight water supply utilities and 23,103 upstream wastewater discharges have been identified and efforts are in progress to utilize data on water utilities, stream flows and wastewater discharges to make computations of the percent wastewater in each utility intake.

Small Flows

Implementation of the Clean Water Act Amendments of 1977 (PL 95-217) has directed considerable attention to the continuing efforts of the Small Flows Research Program. For the first time since the inception of the EPA Construction Grants Program, individual on-site treatment works, such as septic tank - soil absorption systems, are eligible for federal grants if a public entity applies on behalf of these individual units and assures EPA that these systems are properly operated and maintained. The Act specifically requires that, for states having a rural population of 25% or more of the total, 4% of that state's allotted funds must be utilized only for alternatives to conventional sewage treatment works for municipalities which are considered to be highly dispersed in population. Such alternatives include, but are not limited to, septic tank - soil absorption fields, individual mount systems, evapotranspiration beds, self-contained toilets, soil disposal or other systems serving clusters of homes, and alternative sewage collection techniques such as pressure and vacuum sewers. Small communities are the primary targets for implementation of these alternatives due to the often prohibitive cost of providing conventional gravity sewers and centralized sewage treatment facilities.

The impact of the 1977 Clean Water Act on program activities has been: reassessment of research priorities and objectives to meet the immediate needs of engineers, planners, and regulatory authorities; providing technical assistance to a diverse array of people involved with small scale technologies for wastewater treatment and disposal; continuing a series of five Technology Transfer design seminars across the country on rural wastewater treatment alternatives; and implementing two intensive one-week training sessions in Cincinnati and Denver to assist federal and state engineers in the review of facilities plans which employ small-scale or on-site wastewater treatment technology.

The Small Flows Research Program is divided into four main areas of study. These include (1) individual on-site wastewater treatment and disposal technology, (2) management of residuals generated from on-site systems, such as septic tank pumpings (septage), (3) alternative wastewater collection techniques, such as pressure and vacuum sewers and small diameter gravity sewers for septic tank effluent, and (4) institutional arrangements to ensure proper management of individual systems. The common objective which links these various efforts is the provision of adequate protection of public health at a reasonable cost.

Much of the work supported by EPA dealing with on-site treatment systems has recently culminated in the form of a 900-page final report prepared by the University of Wisconsin. This report represents some five years of research effort, and covers many aspects of on-site wastewater treatment systems - their application, costs, theory of operation, design, construction, and management. A continuing EPA grant to the University of Wisconsin is supporting more research into refining construction techniques, rehabilitating failed soil absorption systems, developing methods to improve their performance, and generating data on the treatability of graywater (non-toilet wastewater). A report from the University of Colorado dealing with evapotranspiration beds and mechanical evaporative disposal techniques will be published in the near future. Two new grants have recently been initiated with the states of California and Oregon. These demonstration grants are both designed to collect data from a diverse number of existing on-site treatment systems. The California project will also address the public health aspects of alternative blackwater-graywater systems which have been installed in that state, while the Oregon project seeks to analyze the performance of a wider variety of on-site alternative systems.

Studies of septage handling are continuing through the University of Lowell in Massachusetts. The primary objectives of this study are to determine the impacts of treating septage at a sewage treatment plant, determine how to assess the capacity of a plant to handle this waste, and to investigate other techniques for treating septage at a sewage treatment plant. A report is also being published which summarizes research performed in Maine dealing with alternative septage treatment techniques. A cooperative study between EPA and the National Park Service is investigating composting of wastes pumped from portable toilets and septic tanks.

State-of-the-art reports on pressure and vacuum sewers have been developed, and numerous demonstration projects have been completed that deal with these technologies. Recently, a project was completed that was designed to collect data on cost, performance, operation and maintenance requirements, and type of treatment provided for a number of pressure sewer installations in operation across the country. Another project which evaluated small pressure and vacuum sewers in a single city has also been completed, and the report published.

Since the 1977 Clean Water Act stipulates the requirement of a "management district" or other public body to allow individual systems to be grant eligible, there has been much concern over what forms such an entity might take, how one would be implemented, what the functions of a management district would be, and other legal and institutional questions. In response, the Small Flows Research Program has initiated a comprehensive research contract which will include detailed case studies of existing on-site management practices and policies at the local and state levels. An analysis will be made of the appropriateness, effectiveness, and costs of alternative management approaches under different local situations. Recommendations will be outlined for selection and implementation of management structures and techniques.

For future years, it is anticipated that, while basic research will continue to be supported, more emphasis will be placed upon demonstrating to the public that many of the low-technology, decentralized alternatives are viable, cost-effective approaches to ensuring environmentally sound waste management practices for rural and suburban communities.

Storm and Combined Sewer Section

Control and/or treatment of storm sewer discharges and combined sewer overflows (CSO's) are major problems in the field of water quality management. Every time it rains, in the majority of the oldest and largest cities, tremendous volumes of mixed pollution laden urban runoff and raw sewage (CSO) spill into and contaminate receiving waters. Another problem area during wet weather exists due to man's land development activities which have initiated severe, highly undesirable, and damaging alterations in the natural sedimentation cycle, particularly in local areas, by drastically accelerating the erosion-sedimentation process. Over the past decade much research effort has been expended and a large amount of information has been generated, primarily through the Storm and Combined Sewer Section.

Storm and Combined Sewer research and development effort has been directed to the abatement of pollution loads from CSO. The technology that has been developed for CSO control in many cases has almost direct and complete application for the control of urban stormwater from separate storm drainage systems as well as aspects of sedimentation control.

There has been increased realization that, along with technology develoment, there is a need to better define the actual effects of wet-weather discharges on receiving waters. Results from work in this area are currently being evaluated. Also, because of the high capital cost of treatment methods, there is an increased effort being undertaken to consider other approaches that have much lower capital cost. These include management practices such as improved street sweeping and flushing of sewers during dry weather to reduce the amount of sediment that would otherwise be removed by the next storm and the use of more effective erosion and sedimentation control techniques.

Treatment and Control

Due to adverse and intense flow conditions and unpredictable shock loading effects, it has been difficult to adapt existing treatment methods to storm-generated overflows, especially the microorganism-dependent biological processes. The newer physical/chemical treatment techniques have shown more promise in overcoming these adversities. To reduce capital investments, projects have been directed towards high-rate operations approaching maximum loading boundaries by using the swirl, microstrainer, high rate filter, and dissolved air flotation. These processes, or combinations of these processes, can be adjunct to the existing sanitary plant or serve as remote satellite facilities at the outfall.

At Lancaster, Pennsylvania, as shown in Figure 21, construction has been completed on a 24 ft. diameter swirl CSO regulator/solids separator with a smaller 8 ft. diameter swirl degritter in series to degrit the swirl regulator underflow prior to its entry to the interceptor pumping and sewer system. The swirl system will serve a drainage area of 135 acres.

At the treatment design flow of 25.8 mgd which represents a six in one year storm frequency, 65 percent suspended solids removal is estimated. The device is capable of functioning efficiently over a wide range of combined sewer overflow rates

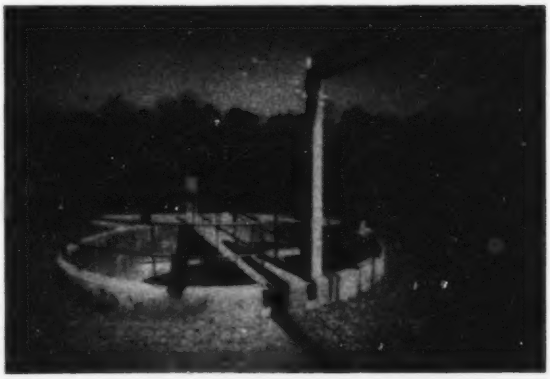

Figure 21. Swirl Regulator/Solids Separator at Lancaster, Pennsylvania.

and can effectively separate suspended matter at a small fraction of the detention time required for sedimentation.

A helical type regulator-separator has also been developed based on principles similar to those of the swirl. The helical is beneficial because of its low depth and because its separation action is created by merely an enlarged bend in the sewer line. Construction of a full scale swirl and helical regulator, to be used in a comparison study, was completed this year near Boston, Massachusetts. Post-construction evaluation is now underway.

Other physical processes with or without chemicals, such as fine screens, high-rate filters, sedimentation, and dissolved air flotation, have been developed and demonstrated in the program.

Source Control and Low Structural Cost Approaches

Nonstructural and low structurally intensive alternatives, termed best management practices (BMPs), offer considerable promise as the first line of action to control urban runoff pollution. By treating the problem at its source, or through appropriate legislation curtailing its opportunity to develop, multiple benefits can be derived. These include lower cost, earlier results, and an improved and cleaner neighborhood environment.

The greatest difficulty faced by BMPs is that the action-impact relationship is almost totally unquantified. It is clear that onsite storage, for example, can be closely related to reduced downstream conduit requirements but the net water quality benefits are far less defined. Similarly, cleaner streets and neighborhoods and enforced legislation will eradicate gross pollution sources but to what limit should they be applied and who will bear the cost? The final answers of cost effectiveness will not be found short of trial implementation. Key demonstration projects in this regard have been awarded this year. At Belleview, Washington, and Orlando, Florida cost-effectiveness of various BMPs will be evaluated. Austin, Texas has been chosen to demonstrate various types of porous pavements to evaluate their effectiveness in the control of both flooding and pollution from urban stormwater runoff.

Other significant BMP demonstrations projects have been ongoing throughout the year and have yielded important results. A study at San Jose, California has developed sampling procedures to test street cleaning equipment performance in real-world conditions. The street cleaning equipment tests showed that different test area conditions affected performance more than differences in equipment type.

The comparison of runoff pollutant concentrations with recommended water quality criteria showed that the heavy metals - cadmium, chromium, lead, mercury, and zinc - as well as phosphates, BOD, suspended solids, and turbidity exceeded the recommended criteria. That does not necessarily mean that a problem exists, but a problem may arise for these parameters, and they should be investigated further in receiving waters. The study showed that aquatic life can be adversely affected by more pollutants than affect other beneficial uses.

The concentrations of many pollutants in the runoff samples were greater than in secondary treated sanitary sewage effluent. Annual yield comparisons showed that the yields for lead, chromium and suspended solids were greater in the runoff than in the treated secondary effluent. Thus, urban runoff may cause some greater "short- and long-term" receiving water pollution problems than the treated effluent. The implication here is that runoff treatment may be a more effective control measure than improvement in the partially treated sanitary sewage effluent.

An investigation of periodic sewer flushing during dry weather for first flush relief is currently under way at Boston, Massachusetts. A set of generalized procedures for estimation pollutant loadings associated with dry weather sewage solids deposition in combined sewer systems has been prepared to provide planners, engineers, and municipal managers with technical information so that they can make intelligent informed decisions on potential sewer flushing programs in combination with other combined sewer management controls.

Another project currently ongoing at San Francisco, California, is concerned with the development of an automatic operational model for real-time control of in-line (in-sewer) storage and routing of storm flows to make maximum use of existing interceptors and sewer line capacity.

Integrating Flood and Erosion Control Technology with Pollution Control Technology

Careful consideration must be given to land use planning since urbanization accelerates hydrograph and pollutograph peaks and total loads by creating impervious surfaces for pollutants and water to run off from. This causes excessive water pollution, erosion, sedimentation and flooding. Discreet selection of land management techniques can reduce drainage and other downstream control costs associated with these problems.

Established flood and erosion control technology must be integrated with pollution control technology so that the retention and drainage facilities and other nonstructural or low-structural management techniques required for flood and erosion control can be simultaneously designed for pollution control. Until this is done, the high cost implications for wet-weather pollution abatement will continue.

The control of erosion from construction and developing sites will have a major impact on the total pollution loads imposed on receiving waters. Current estimates indicate that approximately 1500 square miles of the United States is urbanized annually. All of this land is exposed to accelerated erosion.

Projects at Lake Tahoe, California, and Columbia, South Carolina, were completed this year and provide guidelines for cost-effective methods for controlling erosion and resultant siltation during urbanization in their respective geographical areas.

At Lake Tahoe, the soft, sandy soils containing nutrients and surrounding the lake wash into it during construction activities, speeding eutrophication. Figure 22 shows typical conditions in a hilly area where roads have been cut into the landscape. Figure 23 shows the area after erosion control measures were taken as part of the demonstration project. The willow wattling (i.e., the packing of lengths of brush – in this case willow, but any quick rooting and sprouting species can be used – into continuous thick cables partially buried across a slope at regular contour intervals and supported on the lower side by stakes) and rock wall provide mechanical stabilization. Grasses have been planted to provide interim erosion control and native hardwood plants have been planted in addition to the willows to provide permanent cover and stabilization.

Mathematical Models

Models are needed to predict the time varying rate of runoff and the runoff composition when there is a storm. The calculation of these parameters is useful in the planning, design, operation, and control of wet-weather control systems. The program has developed a number of models ranging in complexity from relatively simple types that require only a calculator to the sophisticated Storm Water Management Model (SWMM) which requires a conventional computer.

Work is continuing to improve these models with incorporation of a variety of subroutines to provide

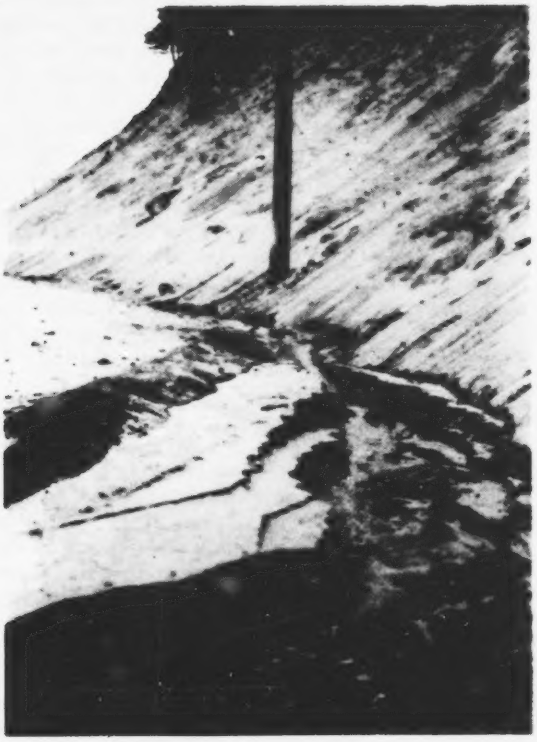

Figure 22. Lake Tahoe Construction Activity Before Implementation of Erosion Control Measures.

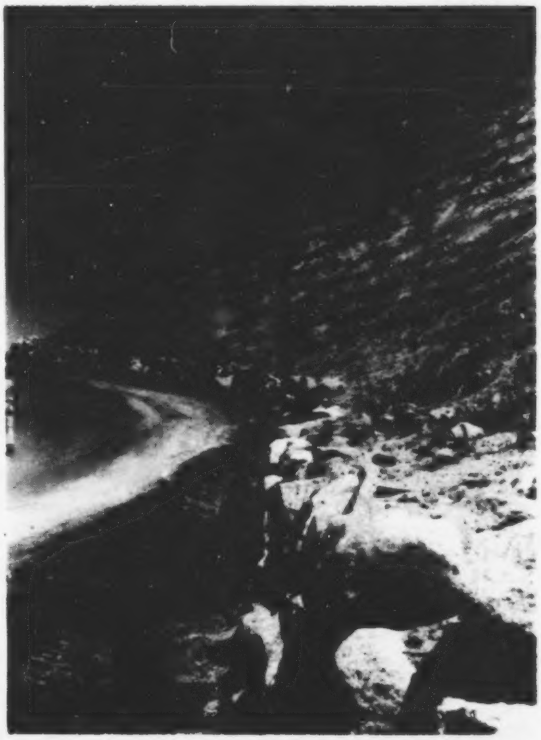

Figure 23. Lake Tahoe Construction Area After Erosion Control Measures were Taken.

greater latitude for the users. They are being utilized widely here and in foreign countries.

Receiving Water Impacts

Data on the environmental impacts of urban runoff are being gathered as a first step in developing methodology to quantify pollutant stress and evaluate the impact in relation to receiving water standards and desired uses. Projects at Seattle, Washington, and Milwaukee, Wisconsin, indicate that one of the most widespread problems of urban runoff lies with the settleable particulates as benthic deposits. In the Milwaukee River, resuspension of sediments has been shown to cause dissolved oxygen problems, and the removal of these sediments combined with conveyance-storage-treatment of combined sewer overflows was found to be the pollution abatement alternative which provides the most significant improvement in water quality as a function of cost. In the Seattle area, suspended solids from combined sewer overflows increase the turbidity in the water column and form sediment deposits containing increased concentrations of metals, oils, and greases, and total chlorinated hydrocarbons. Also, bottom organism and biomass characteristics in these deposits are different from bottom areas not influenced by the urban runoff. In an attempt to track the fate of the suspended materials discharged to flowing streams, modeling studies using sediment transport relationships adapted to urban runoff particulates are underway at selected sites to determine where the solids are deposited.

Because of regulated flows, physical characteristics of the stream, or other unique features, long term deposition of solids may not be the cause of the most significant pollution problems. Immediate impacts such as were determined in the Chattahoochee River below Atlanta, Georgia, where the dissolved oxygen reached a low of 1.5 mg/l and violated stream standards as a result of a summer thunderstorm may be more critical. A nationwide survey of continuous dissolved oxygen monitors is underway as part of a study to correlate this type of dissolved oxygen deficits which occur in receiving streams below urban areas during wet weather storm events.

In an effort to catalog existing data, a nationwide assessment of receiving water impacts from urban stormwater pollution has been initiated to identify inpacts and relate the types of potential impacts to the characteristics of urban areas and their receiving waters. This assessment will locate situations in which urban runoff problems are likely to require control.

Research Reports

Over one dozen research final reports were published this year on various subjects pertinent to the program. One of the most important was entitled URBAN STORMWATER MANAGEMENT AND TECHNOLOGY - UPDATE AND USER'S GUIDE, see Figure 24. The report contains thorough cost and efficiency evaluations of CSO and urban stormwater control projects completed since the original 1974 SOTA review.

Figure 24. **Research Final Reports - On the Left is the 1974 SOTA Review and on the Right is the Most Recent Update Entitled "Urban Stormwater Management and Technology-Update and User's Guide," EPA-600/8-77-014.**

Systems and Economic Analysis Section

This group carries out a wide variety of mathematical and statistical analyses in support of other efforts within MERL.

Recently a computerized optimization procedure called EXEC/OP was developed for use with the EXECUTIVE program for preliminary design and cost estimation of wastewater treatment process systems. EXEC/OP is an efficient computational procedure for identifying the set of designs which optimize cost, energy consumption, land utilization, or some other objective. Up to 40 alternative system designs that are with in a specified percent of any objective such as cost, energy, etc. can be identified. A computational technique known as implicit enumeration is used in EXEC/OP. The optimization procedure is set up by specifying a number of stages through which wastewater and sludge streams flow in a specified pattern. Each stage contains a number of optional processes from which only one can be selected to form a single system design. All feasible system designs must produce an effluent discharge stream equal to or better in quality than the effluent standards supplied as input to the program. Design and/or operation decisions for each process are not continuously variable but must be discreetly specified and treated as alternative processes within each stage. Because of the special requirements of EXEC/OP, several of the EXECUTIVE subroutines have been revised and upgraded. These include models for the activated sludge process, aerobic digestion, heat treatment of sludge, and truck transport with land disposal of sludge. Methodology for performing multi-objective analysis has been developed. The 1977 Amendments to the Clean Water Act permit trade-offs between cost, energy consumption, and other criteria. The multi-objective optimization methodology shows how this requirement can be rationally approached.

Uptake of heavy metals, such as zinc and cadmium, from sludge amended soils by various food crops is an important but poorly understood phenomenon. Various modeling efforts have been initiated in an effort to better understand the role of particular variables in predicting the amount of plant uptake to be expected. An ionic equilibria digital computer program was developed to calculate the concentrations of all ionic species at equilibrium from mass balance, electroneutrality, and stability relationships. The Newton-Raphson method of root finding and Gaussian elimination were used to solve the system of linearized equations. A second simpler ionic equilibria program was developed for the case where pH is an input variable. A digital computer program for numerically integrating the equations for flow of water through one-dimensional non-saturated soil was developed. The time increment required for achieving adequate accuracy was about 10-15 seconds which limits the practical use of the program for studying infiltration over a period of many years. Finally, a model capable of predicting heavy metal uptake over long periods of time was developed but the form of the relationships used were no better than educated guesses.

To better understand the governing relationships, experimental measurements of Zn and Cd uptake by corn from three sources were statistically analyzed. The analysis showed that the concentration of both Zn and Cd in the soil was a linear function of the total amount of metal applied to the land (Figure 25). The amount found in the soil was only a fraction of the total amount applied, suggesting that mobility of the metals is highly dependent on the soil type. Metal concentration in the corn leaf was a linear function of metal concentration in the soil for both Zn and Cd although the Cd measurements showed much greater variability than the Zn measurements. In one case, yield was found to be a secondary predictor; the uptake increasing somewhat with yield. Grain metal concentration was related to soil metal concentration by a relationship similar to the Freundlich isotherm where the rate of change of grain metal with soil metal decreases continuously as the soil metal concentration increases. For one location, regressions between grain metal concentration and total or annual amounts applied were too weak to statistically support one or the other predictor as better. Analysis of two additional sets of metal uptake data showed similar results except that the Cd uptake by corn grain was significantly greater in one set than the other two. The reason for the difference is not known but might be related to the corn variety or the type of soil. Current plans are to similarly analyze all available plant uptake data with the objective of developing a useful heavy metal uptake and metal mobility model.

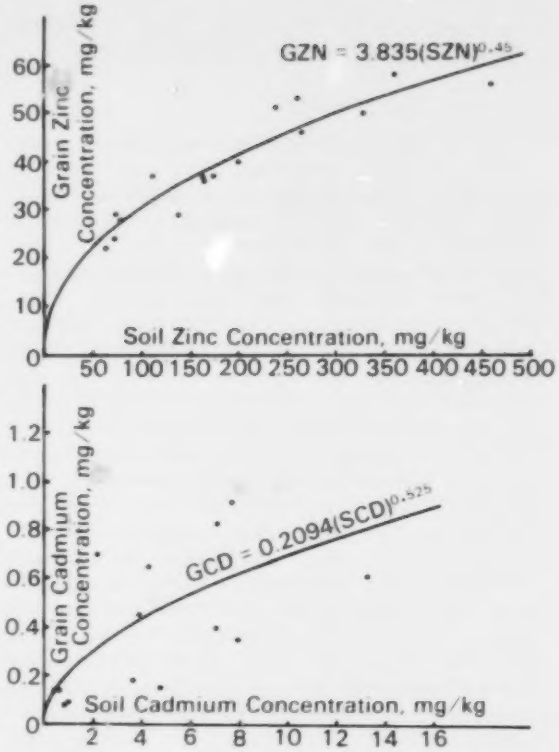

Figure 25. Relationship Between Soil Metal and Corn Grain Metal Concentrations from Experimental Field Experiments on Sludge Amended Land.

Technical methods for estimating the loss of toxic volatile organic compounds from the activated sludge process to the atmosphere were studied and recommendations for an experimental program were made. The principal recommendation was for measurement of Henry's Law constant at the low concentrations characteristic of wastewater.

A computer program called CROM has been developed for estimating the annual operation and maintenance costs associated with the circuit rider method of operation for groups of small, independent wastewater treatment plants. Separate costs for materials and labor are calculated. This program makes it possible to economically evaluate the various route systems that might be followed in order to check and service any group of plants in a certain area, thereby providing a means for determining the least cost plan of circuit rider operation. This procedure is intended to be part of the framework for a simulation model that computes the operation and maintenance cost for several operational modes of groups of small treatment plants. The expanded model will be capable of determining least cost operation and maintenance alternatives for groups of plants located in various regional situations.

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TREATMENT PROCESS DEVELOPMENT BRANCH

BIOLOGICAL TREATMENT SECTION

The prime objective of this group is to develop processes for achieving requirements for the National Pollution Discharge Elimination System relating to municipal wastewater. Over the past decade efforts have been devoted to development of oxygen aeration, lagoon performance, control of the nutrients nitrogen and phosphorus, microbial degradation, and upgrading of existing municial treatment facilities. Major technological advances in these areas have been reported in USEPA's Environmental Protection Technology Series publications, the professional literature and ERIC publications.

Currently, efforts are in a transition stage away from state-of-the-art processes and towards approaches that evidence savings in energy and resources.

Aeration Technology

Clean water oxygen transfer tests conducted by Los Angeles County on six generically different submerged air aeration systems suggest substantial savings in energy may be possible with recently developed fine bubble devices over the long-standing coarse bubble options. The second phase of this project will evaluate several of the more promising systems under process field conditions in activated sludge service. The process studies will determine the extent to which operation in wastewater (i.e., mixed liquor) decreases the high oxygen transfer efficiencies observed with fine bubble equipment in clean water, and whether the fine porous media of some of these devices is subject to rapid headloss buildup and unacceptable maintenance requirements for cleaning. Upon completion of the project, recommendations will be made to the Construction Grants Program concerning the broad application of fine bubble aerators in municipal treatment.

ABF Process

An evaluation of a full-scale municipal activated biofilter (ABF) system is underway at Helena, Montana. ABF employs a unique flow regime consisting of a redwood media trickling filter tower followed by a short detention activated sludge unit. Settled sludge from the activated sludge clarifier is recycled to the tower, rather than to the head of the aeration tank in the conventional fashion. This hybrid configuration reportedly results in excellent process stability under varying loads and substantial economies in capital costs contrasted to either single-stage attached growth systems or two-stage attached/suspended growth systems that recirculate settled sludge directly to the activated sludge stage. This project will for the first time stress a full-scale municipal ABF installation to the organic and hydraulic design conditions recommended by the manufacturer.

Lagoon Solids Control

Two successful demonstrations of algae removal from lagoon effluents have been completed. At Veneta, Oregon, a full-scale rock filter was able to consistently reduce lagoon system suspended solids levels of 22-105 mg/l down to 7-14 mg/l. Full-scale intermittent slow sand filters at Mt. Shasta, California; Moriarty, New Mexico; and Ailey, Georgia produced effluent residuals of 8-17 mg/l for BOD and 13-18 mg/l for suspended solids. This study also revealed that 25-35% nitrification was occurring across the filters at all three sites.

Disinfection of Wastewater Effluent

Emphasis has been on development of alternative disinfection technology which is environmentally safe and technologically sound. Important information was gathered in four major research areas: (1) chlorination/dechlorination; (2) ozonation; (3) ultraviolet irradiation; and (4) support reseach, including indigenous virus inactivation and non-volatile organics analysis of disinfection effluents.

Chlorination/Dechlorination

An optimized pilot chlorination system was evaluated in parallel with several full-scale treatment facilities. Data indicate that improved disinfection efficiency is possible in a well-designed dosing-contact system with a significantly lower applied dose, and decrease in acute fish toxicity is directly proportional to the decrease in the chlorine residual.

A dechlorination study with Los Angeles County has revealed that dechloration with sulfur dioxide can be reliable and cost-effective. Reaeration and pH adjustment are not required in the vast majority of cases. However, total coliform after-growth appears to be a pervasive problem, and its solution is presently obscure.

Ozonation

Substantial progress was made in the in-house ozone contactor evaluation. Four contactors have been studied so far: a packed column, jet scrubber, pressure injector, and a bubble diffuser. The bubble diffuser shown in Figure 26 is by far the most efficient contactor both with respect to ozone utilization and coliform reduction efficiency. Realistic costs for ozone disinfection, based on results from the pilot work, have been developed.

The full-scale study of the cost-effectiveness of disinfection with ozone generated from air has been completed at the Estes Park, Colorado facility. A final report will be available soon.

Ultraviolet Light

Excellent progress was made in the full-scale demonstration project at Northwest Bergen County Sewer Authority, New Jersey. The prototype ultraviolet unit has been operating continuously for 6 months without any major equipment malfunction or degradation in disinfection efficiency. The mechanism which continually wipes the quartz tubes clean has

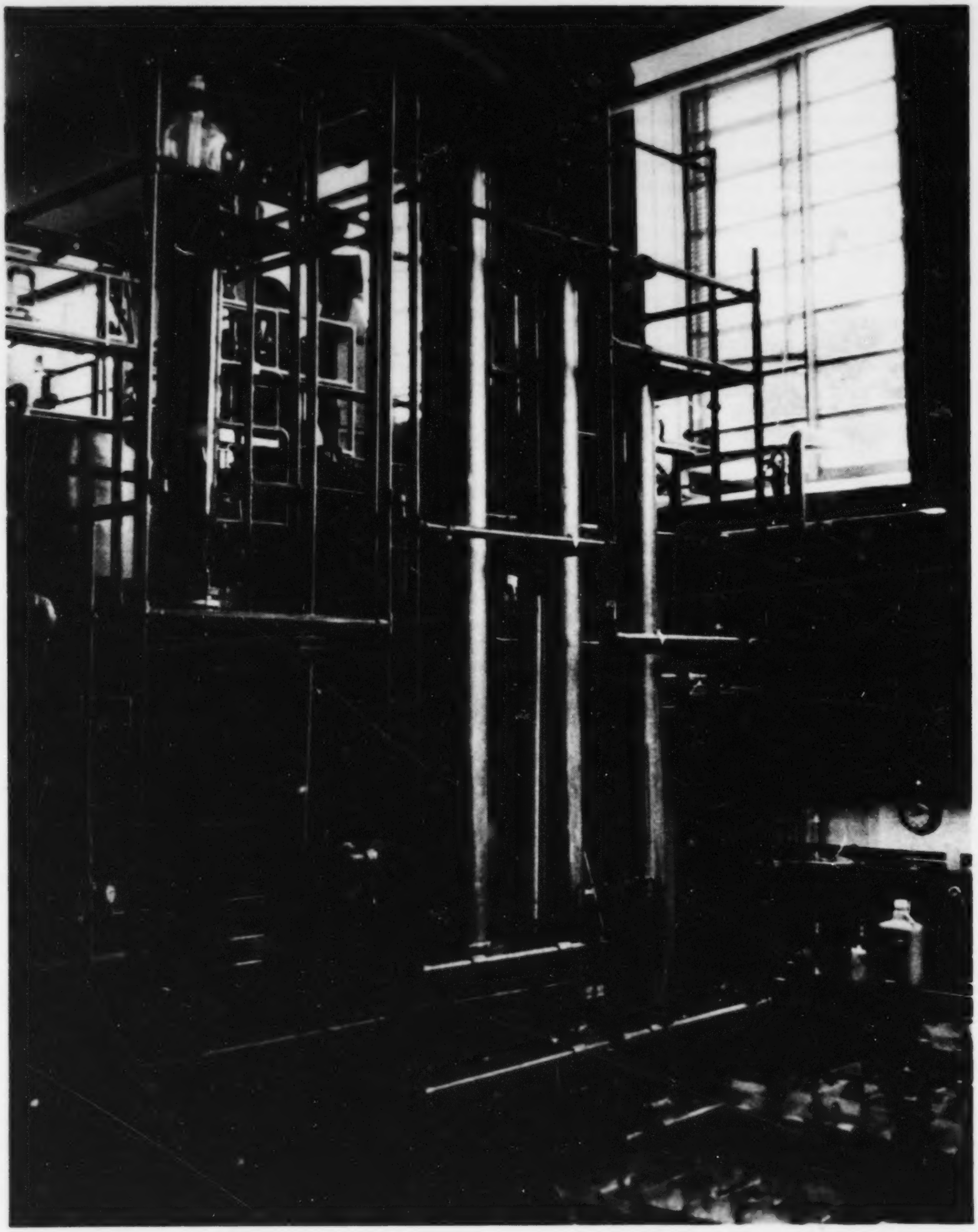

Figure 26. Pilot Plant Ozone Contactors.

functioned extraordinarily well. Preliminary cost analyses indicate UV may be competitive with chlorine as a wastewater disinfectant. Photoreactivation may be a problem, but more information needs to be generated. Basic studies are being conducted at the University of North Carolina to quantify the effect of applied UV dosage on microorganism reduction.

Disinfection Support Research

Oak Ridge National Laboratory has been studying the non-volatile organic fraction of primary and secondary wastewater effluents disinfected with chlorine, ozone, and ultraviolet light. Ultraviolet light, whether used on primary or secondary effluent, has so far exhibited little effect on the non-volatile fraction. Ozonation of secondary effluent apparently destroys some organic constituents and increases the oxidizable components. Chlorination of secondary effluent also destroys some UV-absorbing and oxidizable constitutents and forms several other constituents. Similar observations were noted in primary effluent. One sample of chlorinated primary effluent exhibited highly mutagenic properties, whereas none of the treated secondary effluents were mutagenic.

A study by the Carborundum Company has indicated that chlorine, ozone, an ultraviolet light all display to some extent the ability to inactivate indigenous animal viruses in secondary and tertiary effluent.

National Symposium on Wastewater Disinfection

In September, 1978, a symposium on wastewater disinfection was held in Cincinnati, Ohio. All the above EPA Grantees and Contractors presented progress in their specific research areas. The conference was attended by 250 professionals in the field. Arrangements for printing of the Proceedings are being made, and should be available to the public by January or February, 1979.

PHYSICAL-CHEMICAL TREATMENT SECTION

Toxics Control

It has long been suspected that the tens of thousands of organic and inorganic compounds which society now uses in the billions of pounds per year have left their mark on the environment. In the opinion of many oncologists, human exposure to chemicals in the environment may account for the major cause, up to 85%, of cancers in humans. These suspicions have been amply confirmed during the past few years by the exquisite analytical capabilities of gas chromatography and mass spectrometry which have identified hundreds of compounds wherever they have been sought in the environment. Because so many of the compounds are toxic or carcinogenic to humans and aquatic life, the Agency has mounted a major research effort whose objective can be broadly described as toxcis control. Emphasis of the research has focused on a list of 129 organic and inorganic compounds which have become known popularly as the priority pollutants. It is obvious however, that this list will expand to include other compounds, thus virtually the entire gamut of synthetic chemical compounds is suspect until exonerated.

The research activity of the Section is concerned with toxics in the publicly owned wastewater treatment plant. The research falls into several distinct categories, as follows: (1) development of a data base on the occurrence and concentration of the priority pollutants entering the Nation's wastewater treatment plants. Thus, a grant has been awarded to the University of Washington which will cooperate with the Georgia Institute of Technology to survey some 25 municipal plants for toxic (129 priority pollutants) in the influents, after primary treatment, and in the effluent discharge before and after chlorination (if practiced). Sludges will also be analyzed. A variety of plants containing various compositions of industrial/domestic flows and treating the wastewaters by a variety of processes will be surveyed. From this there will emerge the beginnings of a data base which will provide information on influent occurrence and concentration, removals currently being obtained by a variety of treatment processes and an evaluation of the toxics in sludges. Certain compounds tend to accumulate in sludge at concentrations 10 to 1000 fold higher than the influent. A corollary, yet extremely important objective of this study is to develop and verify the analytical methods that will be used in the survey. Surrogate tests for toxicity of the effluents, such as Ames Test and acute fish toxicity will complete the study.

The data base on the occurrence and distribution of metals (some 14 are included in the list of priority pollutants) is being expanded by several projects now either completed or underway. Metals discharged to a treatment plant have a special significance since, in the absence of proper precautions, they may be cycled from one medium of the environment to another; since metals cannot be destroyed, they can only be contained. Thus, removal from the liquid flow in a plant merely concentrates the metals in the sludges, in very much higher concentrations than the influent, thus placing restraints on the manner by which the sludges are finally disposed.

Existing information on metals is being obtained by a grant with the University of Tennessee which will locate and evaluate local, state and federal data on metals that will ultimately permit an assessment of the sources of the metals discharged to wastewater treatment plants. A complementary study is being conducted by Purdue University which is currently performing a detailed survey of the City of Kokomo, Indiana. Data on selected metals and cyanide are being collected through a comprehensive sampling and analytical program for stormwater, residential and industrial flows to the treatment plant. The treatment plant itself is also being sampled intensively. This study will thus provide the date base for formulating regulations for control of metals, which are likely to include pretreatment at industrial sites, improved removals of metals at the treatment plant and the manner by which the metals contaminated sludges are finally disposed.

Another objective in the research on toxics is (2) the treatability/removability of these compounds by treatment processes. The subject of treatability is treated separately in this report under the heading *Treatability of Hazardous Compounds*. The treatability of selected toxic compounds is being examined in-house on a pilot plant scale. Five organic compounds are being added to raw sewage prior to treatment by alum clarification, dual media filtration and granular activated carbon. Automatic composite samplers, designed to avoid loss of volatile organics, collect samples at appropriate locations in the system and analyzed by gas chromatographic procedures. Premilinary data indicate that, from an influent averaging 120-180 $\mu g/l$ of each compound, reductions across the alum-polymer clarification unit range from 11% for dimethylphthalate to 66% for ethylbenzene. Some of the volatile substances are undoubtedly lost to the atmosphere during air-liquid contact. No further removal occurs during dual-media filtration.

A five-minute (empty bed) contact time carbon adsorber operating on dual-media filter effluent maintained the concentration of the five organics to less than detectable levels for only 1-2 weeks. The order of breakthrough to 25% of influent concentration of the compounds assayed was, first, carbon tetrachloride, then, trichloroethylene, dimethylphthalate, nitrobenzene and ethylbenzene. Only carbon tetrachloride and trichloroethylene had begun to break through the carbon at a contact time of 15 minutes after five weeks on stream. Complete loading data from the column operation, together with laboratory equilibrium tests will help to clarify the role of activated carbon in the removal of toxic organics from municipal wastewaters.

A third and final overall objective of toxics control is (3) evaluation of treatment processes for removal of toxics and development of proess improvements for removal. A start in this direction is a research grant with the University of Michigan which will investigate the addition of powdered activated carbon to the aeration process in activated sludge plants. In anticipation that process economics may be affected by the cost of powdered carbon, a study with Stanford Univeristy was undertaken to seek a cheaper but equivalent powdered carbon to current commercial products. A variety of waste carbonaceous sources, other than coal or wood, is being treated by processes including pyrolysis and activation to produce a powdered activated carbon. The two major reactions will be optimized and the resulting carbons matched by performance against commercial products.

ULTIMATE DISPOSAL SECTION

Municipal wastewater sludges contain insoluble and adsorbed impurities resulting from wastewater treatment. Wastewater sludges also contain human wastes, pathogenic organisms and higher life forms, and industrial wastes ranging from highly toxic substances to innocuous materials such as food wastes.

The primary responsibility of the Ultimate Disposal program is to find environmentally acceptable and cost-effective approaches for treating and disposing of municipal wastewater sludges. Therefore, the objectives are to improve, adapt, and develop the processing, treatment, and conversion technology for the conditions expected to prevail in the near future and during the next decade.

The sludge research program is divided into the following subdivisions:

1. sludge processing and treatment
2. sludge conversion
3. Beneficial utilization and disposal

Sludge processing and treatment includes all of the steps from the first appearance of sludge until it enters the disposal step. Anaerobic digestion is an example. Sludge conversion is any process that changes the nature of the sludge so that it is no longer perceived as sludge. Composting is an example. Beneficial utilization includes any constructive use of sludge. Landspreading of sludge on soil for beneficial use of its fertilizer and organic content is an example of constructive use.

Sludge Processing and Treatment

The heavy metals content of sludges, particularly that of cadmium, tends to inhibit exploitation of land disposal as an attractive method of final disposal of sludge solid. The technical and economic feasibility of removing heavy metals from sludge using a hot acid process has recently been studied under a contract with Walden Research. The process involves acidification of the sludge (pH 2-3) and heating to temperatures below boiling (about 95°C). Test results show that the process can solubilize the cadmium and the other heavy metals in varying percentages. In addition, the process improves the dewaterability of the sludge and destroys all pathogens. A preliminary economic analysis of the process indicates that it is cost-competitive with alternative stabilization and conditioning processes. A demonstration of the heavy metals removal processes at pilot scale is planned.

The use of solar energy in wastewater treatment operations continues to receive attention. The desk-top project completed by Environmental Systems, Inc., showed that solar heating of anaerobic digesters was economically and technically feasible through the United States. This concept will be utilized at full scale at Wilton, Maine. The Wilton plant will be the first to demonstrate innovative energy savings concepts that will make use of an integrated energy system of solar energy, digester methane gas, and process heat recovery. A contract jointly supported by EPA and the Department of Energy will document all aspects of the Wilton solar energy experience.

The progress of wastewater treatment technology has been rapid in recent years. The result has been the generation of new types of sludges and the development of new processes to handle both new and conventional sludges. The design engineer is often virtually without information when he must design new facilities. A substantial portion of our effort has gone into filling this information gap.

An example of a study inaugurated to provide vitally needed design information is the survey of the impact of phosphorus removal sludges on wastewater treatment plant operation. Removal of phosphorus from wastewater normally entails precipitation of phosphates by the addition of a chemical, generally either lime or a salt of iron or aluminum. A consequence of phosphorus removal, therefore, is the production of sludge which is laden with chemical precipitates. Sludge mass is increased and its properties are changed, usually for the worse. The survey of 174 plants removing phosphorus by chemical addition, produced very useful information. The dominant chemical used is iron, either as a ferric salt or a waste pickle liquor from metal treatment. Lime is least used. Iron salts produce the least impact on sludge processing. Generally sludge processing facilities such as anaerobic digesters and vacuum filters become overloaded. An unexpected complaint was the increase in energy requirement. More sludge produced, often of lower solids content, means that more fuel must be used to raise it to digestion temperatures or to incinerate it. The increase in costs and overloading of equipment, particularly dewatering equipment, has produced a definite movement towards land application of liquid sludge.

A similar study has been made of the use of heat treatment for conditioning sludge. Controversy has arisen as to whether the negative impacts (odor production, high BOD return stream, high capital cost) are counterbalanced by the positive impacts (easy filtration, high solids cake, no need for conditioning chemicals). An objective assessment of the process at working heat treatment plants was carried out and results were made available to designers and municipalities. Emphasized was the need for pilot plant operation before design, grit removal, odor control, and a high level of mechanical skill in the work force. Documentation showed the significant increase in cost with decreasing plant size; for example, costs are an exorbitant $260/dry ton of sludge solids for a 1 mgd (3785 m^3/d) plant. The information made available should help prevent overenthusiastic use of the heat treatment process where it really is not needed, and should prevent the design errors (such as inadequate odor control) that have created a negative attitude toward the process.

The need for producing a stabilized sludge that is essentially free of pathogens is another controversial subject. In some cases, such a result is clearly desirable. Thermophilic (ca. 50°C) digestion processes have this effect but have been either unstable or too costly to consider. MERL is supporting development of two stable thermophilic digestion processes that may be close enough in cost to conventional digestion procedures that the economic disincentive to choose a process that produces a pathogen-free sludge will disappear. Cornell University has tested an aerobic digestion process that reaches 50°C without addition of external heat. The City of Hagerstown is going to demonstrate Union Carbide's aerobic-anaerobic digestion process that disinfects the sludge with one day of aerobic digestion (achieves 55°C by using oxygen) and follows it with eight days anaerobic digestion that produces methane.

Sludge Conversion

The U.S. Department of Agriculture's Static-Pile Forced-Aeration Composting Process, developed with MERL and other EPA support, has continued to provide solutions to sludge disposal problems in many areas of the country. Camden's full-scale plant is in operation, and both New York and New Jersey are planning to make extensive use of this process as they phase out ocean dumping of sludge. EPA reports, for example, *A Study of Forced Aeration Composting of Wastewater Sludges*, (EPA 600/2-78-057, June 1978) have received wide circulation.

In some locations, unconfined composting has met with objections. Studies are underway to evaluate within-vessel composting processes. European technology is being evaluated and the cost evaluation of a compost plant that fits conveniently on a river barge is planned.

Thermal conversion processes which offer less pollution potential than incineration have been developed with MERL assistance. Plans are being developed to evaluate starved-air combustion processes that produce a fuel gas and recover energy when these gasses are combusted. EPA's Construction Grants program is providing the capital funds for construction, while MERL will provide funds for an evaluation period. MERL has an evaluation now underway of Duluth's co-incineration plant, where refuse-derived fuel will provide the fuel for combusting sewage sludge.

Beneficial Utilization and Disposal

The options for selection of systems for treatment, handling, and disposal of sewage sludge are numerous, but the choices of ultimate receptors for the sludge are few. Land is the only acceptable receiver. Sludge may be utilized in or near the surface soil to enhance soil productivity or it may be sequestered beneath the surface soil. The former offers the opportunity to consume some of the useful constituents of sludge while disposing of it economically in an energy-use efficiency manner. Sequestering sludge in landfills, basins, or trenches offers the possibility of economical disposal where sludge quality or site conditions make landspreading unfeasible. More information is needed for development of technology for utilizing or disposing of sludge under the multitude of sludge-soil-climate-land use conditions that may be encountered in planning and construction of public wastewater treatment facilities.

Plant nutrients and organic matter can be beneficial to soil and make it more productive. Both inorganic and organic components of sludge can, however, be harmful to the environment or hazardous to public health if they are added to soil in excessive amounts. The amount of each component that is acceptable is dependent upon site characteristics and management and regulations.

A sizeable portion of MERL's research effort has been devoted to determining the fate and effects of the nutrients and trace elements in sludge-treated soils. Copper, nickel, and zinc have been identified as metals that are more likely to accumulate to phytotoxic levels in sludge-treated soils. Cadmium is the element of most concern because of its potential adverse effects on human health. It is assimilated by growing plants and is accumulated in the liver and kidneys of the consumer. Lead is of concern if sludge-contaminated forages are ingested by animals. Nitrates can leach into ground water, and both nitrates and phosphates can be transported by surface runoff into streams and reservoirs. Progress has been made in identifying acceptable sludge application rates and appropriate site management techniques for application of specific sludges on specific soil-climate-crop combinations. A grant to Chicago is supporting a study of the accumulative effects of annual sludge applications over a long period of time. After 10 years, cadmium concentration in grain does not appear to be increasing. No phytotoxicity from metals has been encountered. Corn yields from sludge-treated soils are equivalent to, or superior to, conventionally fertilized plots. With MERL support, the Science and Education Administration of the U.S. Department of Agriculture at St. Paul, Minnesota, is developing site management technology to enable the beneficial use of sludge as a soil amendment. Diversion terraces, contour cultivation, and appropriate cropping systems are being used to minimize runoff and leaching of soluble and suspended sludge constituents. Animal feeding of sludge-produced corn silage is being used to determine the effect of the cadmium-enriched feed on animal health, carcass composition, and milk composition.

Toxic organic substances that may find their way into sludge are of increasing interest. The principal known organic constituents of sludge are PCBs and pesticides, but concentrations of persistent pesticides in sludge are usually lower than in soils to which they were applied, so sludge application should be of concern only if sludges with unusually high pesticide concentrations are used. PCBs are adsorbed on soils and have low solubility, plant uptake is negligible, but surface contamination of crops could be significant.

The transmission of pathogenic organisms through sludge use on soil is of concern. At the University of Illinois, under a MERL grant, the effect on the parasite population in worm-free pigs foraging on sludge-treated soils is being studied. Direct feeding of sludge, and feeding of crops from sludge-amended soils at Denver have not produced disease in cattle. An epidemiological study of humans and domestic animals is part of a large-scale utilization demonstration in Ohio being supported by a grant to the Ohio Farm Bureau Development Corporation. This project also demonstrates institutional arrangements and informational activities to involve the public in planning and implementation of sludge disposal projects.

Studies to be initiated in FY 1979 include identification of non-food chain crops that can be produced on sludge-amended soils, and demonstration of sludge use to produce non-food chain crops. Production of food chain crops on sludgetreated soils may not be feasible under all circumstances because of regulations, contaminated sludge, or environmental constraints. In these cases, the production of non-food chain crops such as trees for energy or fiber, or ornamentals may offer an economical and resource-conserving option.

The technology for improving disturbed or impoverished lands with sludge will be improved by data being generated in ongoing studies supported by grants to MSD-Chicago and the Pennsylvania Department of Environmental Resources to study the use of sewage sludge in reclaiming stripmine spoils.

Selected toxic organic substances that may be in sludge will be studied in greenhouse and field plots to determine their fate and effects when they are applied to agricultural soils as a constituent of sludge. Crop uptake and leaching rates will be measured.

A study of landfilling of sewage sludge alone and with municipal refuse will be initiated to identify safe practices and provide management guidance information. The fate of toxic and pathogenic components of sludge under various landfilling practices will be determined.

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DRINKING WATER RESEARCH DIVISION

The Drinking Water Research Division (DWRD) of MERL has the responsibility of determining the occurrence of contaminants and of conducting research and development to establish the water treatment and control technology in accordance with the provisions of the Safe Drinking Water Act of 1974 (Public Law 93-523). The Division maintains liaison with the Office of Drinking Water in the Office of Water and Waste Management to insure that research requirements of the Act can be met in a timely fashion.

The Drinking Water Research Division provides as focal point for the coordination of all water supply research activities located in various geographical locations and organizational units: Municipal Environmental Research Laboratory, Cincinnati, Ohio; Health Effects Research Laboratory, Cincinnati, Ohio; Environmental Monitoring and Support Laboratory, Cincinnati, Ohio; the Environmental Research Laboratory, Athens, Georgia; and the Environmental Research Laboratory, Ada, Oklahoma. The director of DWRD also serves as the coordinator of these functions and arranges for technical assistance to the Office of Drinking Water as well as to the states, to water utilities, and to the general public.

The research is performed in two branches of the Division, the Physical and Chemical Contaminants Removal Branch and the Microbiological Treatment Branch. Descriptions of their activities over the 14 months covered by this report follow. Major issues that have spotlighted the research effort during that time include the investigation of treatment practices to minimize the presence of organics in treated water, the examination of treatment technology and associated costs to reduce contaminant levels to those specified in the National Interim Primary Drinking Water Regulations (NIPDWR), the use of disinfectants other than chlorine and the determination of whether harmful by-products are formed, the removal of asbestos fibers from drinking water, the removal of *Giardia lamblia* from public water supplies not using filtration, the development of rapid methods for the detection of bacteria, the relationship of turbidity to disinfection efficiency, the role of viruses in disinfection, and the evaluation of point-of-use treatment devices.

PHYSICAL AND CHEMICAL CONTAMINANTS REMOVAL BRANCH

The objectives of the in-house and extramural research conducted by the Physical and Chemical Contaminants Removal Branch are to develop economic drinking water treatment unit processes to allow a water utility of any size to meet the Drinking Water Regulations, either those presently effective or those contemplated in the future, and to devise techniques to allow the distribution of water to the consumer without deterioration in quality. To accomplish this, the Branch is divided into five research areas: Inorganic Contaminants, Particulate Contaminants, Organic Contaminants, Economic Analysis, and Distribution System Quality. Discussion to follow will be divided into these five categories and will summarize the research accomplishments from October 1977 through December 1978. At the end of each section will be a list of articles published during that time.

INORGANIC CONTAMINANTS

Jar test and pilot plant studies (Figure 27) were completed on the removal of the trace metals listed in the National Interim Primary Drinking Water Regulations (NIPDWR) by conventional coagulation and lime softening, and research begun on the removal of specific problem contaminants selenium, arsenic, fluoride, and nitrate by other treatment techniques. Except for arsenic, these four contaminants are not effectively removed from water by conventional coagulation and lime softening. Moreover, all four substances occur in ground water and thus are

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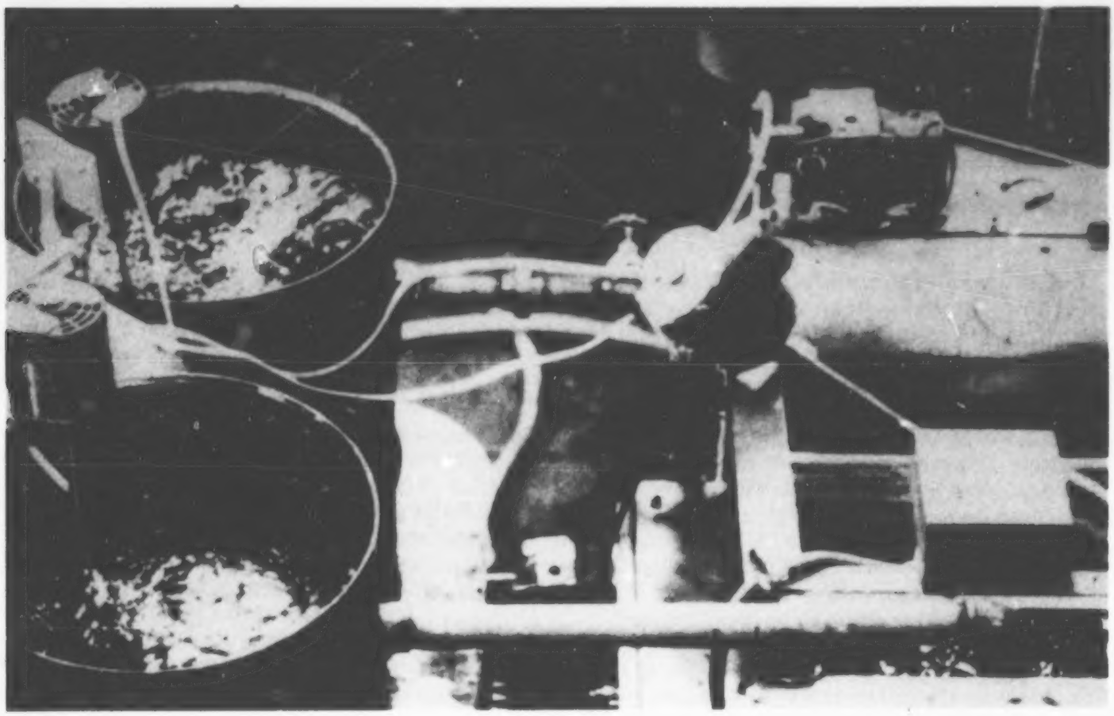

Figure 27. Mixing Tanks for Portable Pilot Plant for Conventional Treatment.

anticipated to present the greatest number of problems to small communities using well water.

Activated alumina, which has been effectively used to remove fluoride from water, was shown to remove both selenium IV and VI from water under certain conditions. The reverse osmosis process was also found to be very effective for selenium removal (90-95 %). Reverse osmosis can achieve very high fluoride and arsenic V removals (90-95 %) and moderate nitrate removal (75-85%) and arsenic III (60-70%). Although reverse osmosis is expensive and not commonly used for drinking water treatment, the technique has certain advantages; it is useful for treating water high in total dissolved solids and having multiple contaminants that cannot be removed by conventional treatment methods.

Field projects to complement inhouse research were funded to investigate the removal of all the inorganic contaminants listed in the NIPDWR from ground water by reverse osmosis; selenium from ground water by activated alumina; and nitrate from ground water by ion exchange and reverse osmosis. All of these projects will provide practical information for the design and operation of treatment systems both small and large to remove these specific contaminants. Economic data will also be developed.

Detailed information on completed jar test and pilot plant studies (Figure 28) for trace metal removal is being published in a series of articles in the *Journal of the American Water Works Association.*

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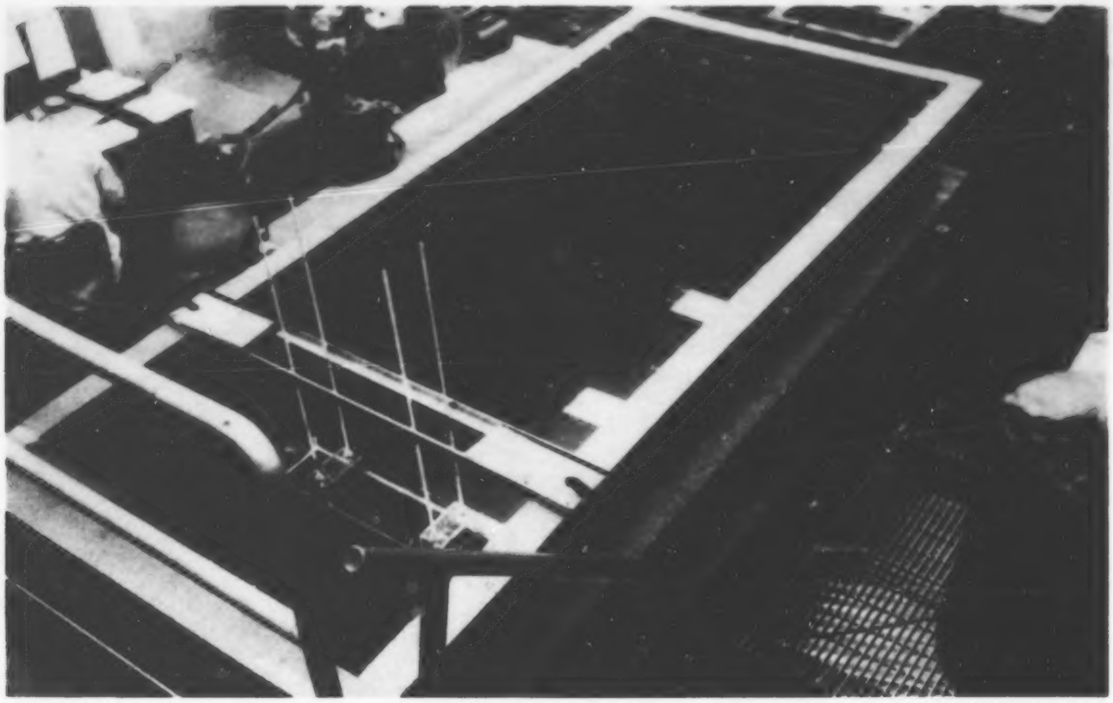

Figure 28. Settling Tank for 2 gpm Coagulation-Sedimentation Pilot Plant.

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PARTICULATE CONTAMINANTS

Particulate removal studies continued for two types of contaminants - asbestos fibers and *Giardia* cysts.

The Drinking Water Research Division has studied granular media filtration for removal of amphibole and chrysotile asbestos fibers at Duluth, Minnesota, Seattle, Washington, and Philadelphia, Pennsylvania. At Duluth, the 30 mgd plant shows amphibole removal consistently exceeding 99%, with filtered water turbidities of 0.04 to 0.05 nephelometric turbidity units (ntu) and amphibole fiber counts of 0.01 to 0.1 × 10^6 fibers/liter (f/l). As a result of one especially severe storm, the amphibole fiber count rose to 1200 × 10^6 f/l. The filtration plant, then operating with sedimentation, reduced the amphibole concentration to 0.048 × 10^6 f/l, while turbidity was being reduced from 14 ntu to 0.05 ntu. Minnesota State Health Department Data show amphibole fiber removals of nearly 99% at new plants in Two Harbors and Silver Bay. Duluth can use conventional filtration with settling or direct filtration (settling omitted). Plants at Two Harbors and Silver Bay are direct filtration plants (Figure 29).

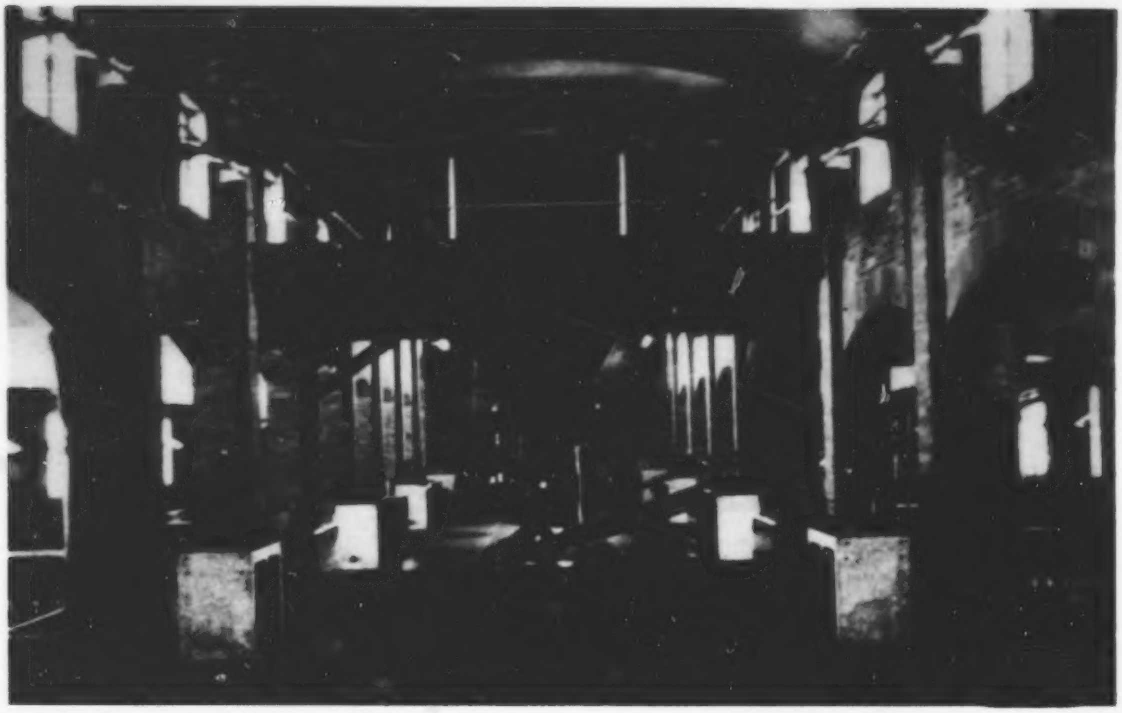

Figure 29. Filtration Gallery at a Major Water Utility.

Three large conventional plants in Philadelphia consistently reduced asbestos concentrations from 10^6 to 10^7 f/l to 0.1×10^6 f/l or less during a five month study period in 1977-1978. Production of a filter effluent turbidity of 0.1 ntu is one of the quality goals at Philadelphia.

The 20 gpm granular media filtration pilot plant treating clear Cascade Mountain water at Seattle effectively removed asbestos fibers when effluent turbidity was below 0.10 ntu. The direct filtration process repeatedly produced water with chrysotile asbestos counts of 0.2×10^6 f/l or less, with numerous samples below limits of detection. Raw water chrysotile content ranged from 1 to 20×10^6 f/l. When filtered water turbidity rose above 0.1 ntu, asbestos fiber count in the filtered water rose dramatically. This study suggests that turbidity may be used as an indicator of effective filter performance for asbestos fiber removal.

Because outbreaks of waterborne giardiasis have been documented only in recent years, information on the removal of *Giardia* cysts at water filtration plants is limited to filtration failures associated with outbreaks.

Filtration for removal of *Entomoeba histolytica* cysts was studied in the 1930's and 1940's. Granular media filtration was effective for *E. histolytica* cyst removal if the water was properly preconditioned first. Minimum preconditioning required was effective coagulation. Sedimentation also aided in cyst removal. Recent laboratory work with *Giardia muris* cysts (a mouse parasite) has shown that coagulation and sedimentation can reduce cyst concentrations up to 99%. One analysis showed the zeta potential (related to electrophoretic mobility) of *G. muris* was negative, a result similar to those for clays and bacteria.

Army research in World War II showed that diatomaceous earth filtration was effective for removal of *E. histolytica* cysts, and two filtration tests with *G. lamblia* cysts indicated that diatomite filtration also removes this type of cyst.

Both previous work and present work with 9 μm radioactive microspheres used as cyst models show that good plant operating procedures are necessary if diatomaceous earth filtration plants are to be an effective barrier to the passage of cysts into drinking water. The filters should be precoated with 0.2 pounds of diatomite per square foot of filter surface, and body feed must be added to maintain the integrity of the filter cake. Filtered water, not raw water, should be used to prepare the precoat slurry.

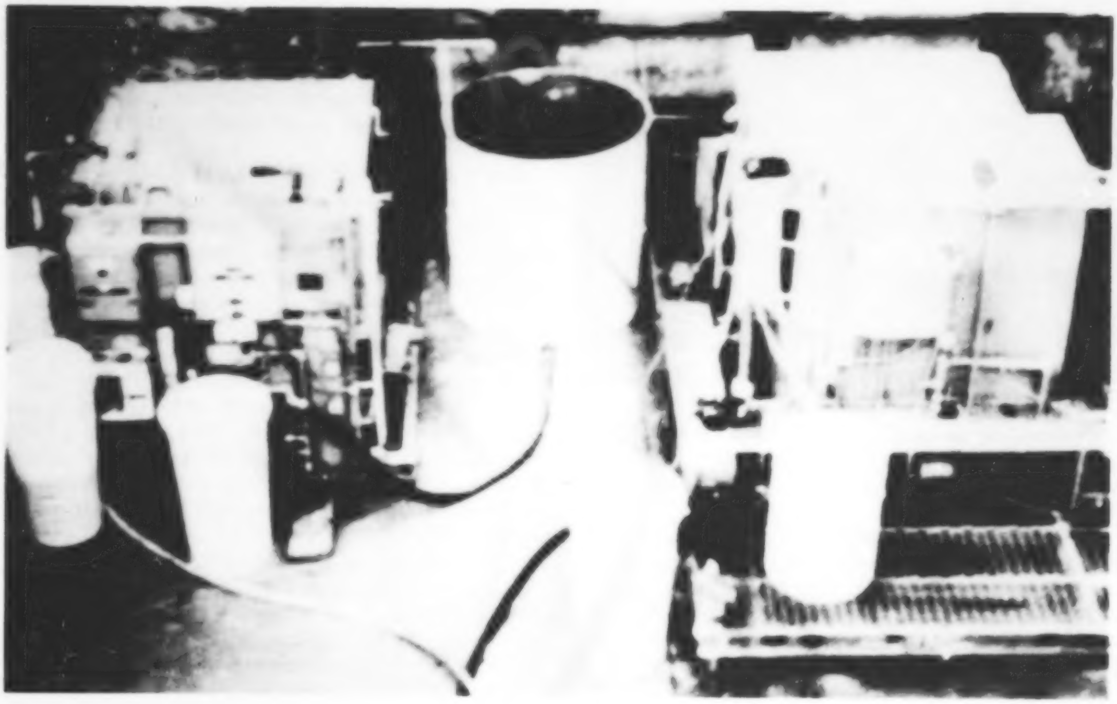

Figure 30. Overview of Portable Pilot Plant for Conventional Treatment.

Studies of *Giardia* cyst removal will continue at the DWRD pilot plant (Figure 30) and at the University of Washington through a research grant.

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ORGANIC CONTAMINANTS

Aeration and adsorption with both granular activated carbon and synthetic resin are treatment processes being evaluated for use where ground waters are contaminated by organic contaminants, e.g. industrial cleaning solvents. Using pilot scale columns, in-house researchers have conducted studies at three New England Water Utilities. Sufficient preliminary treatment data was gathered to warrant an expanded extramural project at Glen Cove, New York (Long Island).

Two documents were prepared in conjunction with the proposed regulation on trace organics in drinking water. One, *Interim Treatment Guide for Controlling Organic Contaminants in Drinking Water Using Granular Activated Carbon,* provides background technical information on the efficacy of several water treatment processes for organic removal (reduction), and the other document, *Operational Aspects of Granular Activated Carbon Adsorption Treatment,* addresses specific questions often asked on this topic.

Analytical efforts are complete on three contractual assignments dealing with the control of trihalomethanes (Figure 31). Two of these projects were pilot scale adsorption studies (one in Lawrence, Massachusetts and the other is in Kansas City, Missouri) and the third examined the effects of altering the practice of breakpoint

Figure 31. Analytical Equipment for Measurement of Trihalomethanes.

chlorination at a lime softening water treatment plant (Huron, South Dakota). The final reports are being prepared.

A major extramural research project report on the current international technology of ozonation and chlorine dioxide usage in drinking water treatment was published. In this report, special attention was given to collection of on-site data for engineering design of treatment systems and to a comprehensive treatise on the organic oxidation products resulting from chlorine dioxide and ozone application. Information is also presented on the use of ozone in combination with granular activated carbon.

Research continued on the combination of ozone and granular activated carbon (GAC) as a means of extending carbon bed life. In house, a pilot-scale project is investigating four parallel systems — oxygen only, high (5.0 mg/L) ozone dose, low (0.5 mg/L) ozone dose and a control. Extramurally, three research projects at Miami, Florida, Philadelphia, Pennsylvania and Shreveport, Louisiana will investigate, at pilot-scale, the combination of ozone and GAC in a variety of raw waters.

Research has continued in the study of organic byproducts of disinfection other than the trihalomethanes. Several aliphatic substituted benzenes which were not normally characterized as increasing on chlorination have been found at higher levels in a chlorinated drinking water than its surface water source. A refined carbon adsorbable organic halogen as chloride (CAOX) procedure was used to examine organic byproducts from humic acid solution treated with chlorine and chlorine dioxide. Chlorine substitution from chlorine treatment is approximately ten times that accounted for by trihalomethane formation. Although it appears to be less than that with chlorine, chlorine substitution is also observed with chlorine dioxide applications at low doses. The halogenated compounds formed from both disinfectants remain as high molecular weight species not amenable to gas chromatographic analysis. The CAOX procedure has been an extremely useful tool in this area of research.

Methodology has been developed to employ glass capillary gas chromatography with flame ionization detection to examine the organic profiles of extracts from water samples. This methodology is currently being used to evaluate granular activated carbon (GAC) effectiveness for removal of organics from both pilot plant and full scale treatment plant operations.

Research has begun to investigate the removal of specific organic compounds using GAC (Figure 32). Isotherm and kinetics data is also being generated to be used for evaluation of GAC adsorption computer models. Initial selection of the compounds to be studied was based on toxicity and occurrence data.

The basic objective of our field investigations efforts is to evaluate and develop water treatment technology that minimizes the presence of potentially harmful organics in drinking water. The research projects involve technology directed at minimizing the concentrations of organic substances associated with the disinfection of drinking water, such as trihalomethanes and precursors, and specific organic substances that occur in the source waters and are not substantially removed by commonly used water treatment methods. The projects also include evaluation of the costs required for a given technology, whenever the scale of the project is large enough.

Current investigations include studies of adsorbents, alternative disinfectants and modification of the points of application of disinfection to minimize organic contamination. Also onsite carbon regeneration technology is under investigation.

Granular activated carbon (GAC) studies involving both full-scale contactors and pilot columns are progressing at a site along the lower Mississippi. Two, six-month phases of full-scale operation of gravity GAC beds using lower Mississippi river water have been completed. One bed was operated as a post-filter adsorber while the other one was operated as a sand replacement system. Preliminary results were reported in 1978 at the AWWA in Atlantic City, New Jersey and at the ACS in Miami, Florida. A recently started third phase incorporates pilot column studies in parallel operation with the full-scale beds.

At a site on the Ohio River, a six-month phase of operating three 5 mgd sand replacement GAC beds and a parallel pilot column utilizing Ohio River

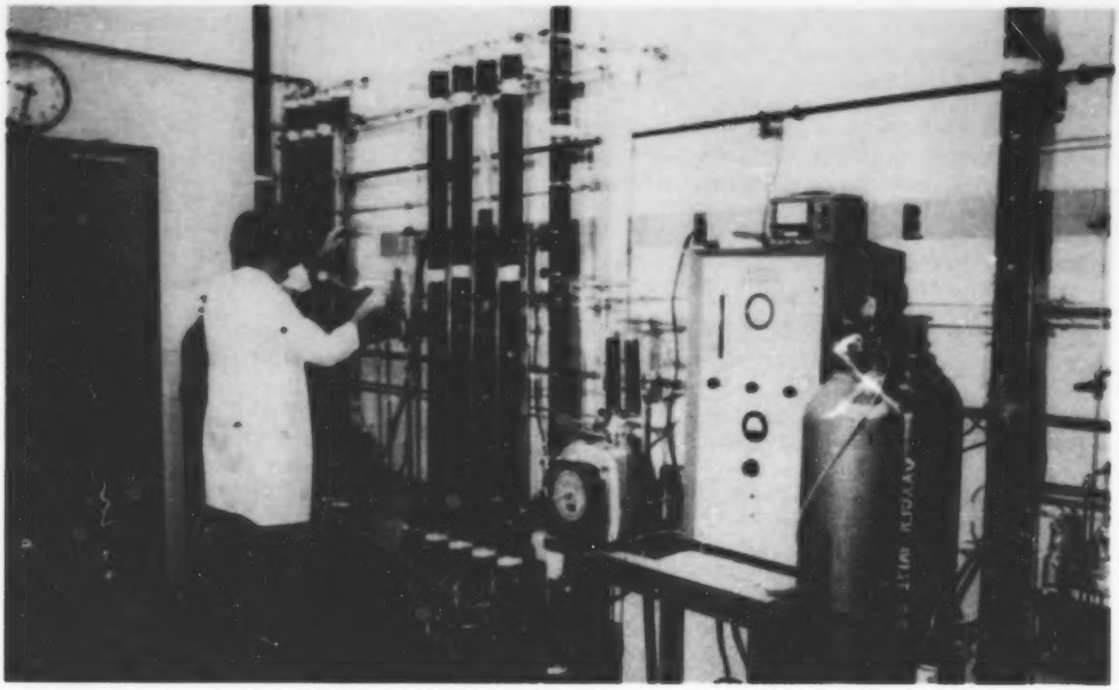

Figure 32. GAC Used to Investigate Removal of Specific Organic Compounds.

source water has been completed. A recently instituted second phase of pilot column investigation involves using two types of carbon operated as post filter adsorbers along with columns operated as sand replacement systems with virgin and once reactivated carbon.

A lower Ohio River study is using the full-scale plant as a control and a pilot plant at this location is being used for comparison of the effects of chlorine and chlorine dioxide disinfection both with and without GAC. Various modes of operation will be evaluated in short term tests and a mode selected for long-term evaluation.

A project designed to conduct full-scale treatment modifications at 7 utilities and to monitor the raw and finished purgeable organic compound levels at 11 utilities has been completed. The project compared the performance of virgin granular activated carbon (GAC) vs. aged carbons, an evaluation of GAC performance of three virgin carbons, several studies to assess the value of moving the chlorine application point, a study to evaluate ammoniation, and a study to compare the use of chlorine dioxide to chlorine as a disinfectant. Data from the 11 utilities was collected monthly from July 1977 through June 1978 and represents the first time such a data bank exists for the Ohio River Valley.

In 1979, full-scale operation of two on-site carbon reactivation systems is scheduled to begin. Both of these regenerators will be fluidized bed and will reactivate carbon that has been used for surface water treatment (one utilizing Ohio River water and the other a Northeast lake).

A study of the synthetic adsorbents XE-340 and IRA 904 as well as granular activated carbon has been completed in Southern Florida. The source water was a ground water containing high TOC and trihalomethane precursor concentrations and specific organics. A final report will be published in 1979. The results of the completed study have been used to initiate a new project using an ozone-GAC system.

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ECONOMIC ANALYSIS

One of the major problems facing EPA in implementing the Safe Drinking Water Act is that of small systems compliance. Small systems (10,000 people or less) may have difficulties in meeting the Act's requirements. Economies of scale insure that unit costs for water provided by small utilities are higher than in larger utilities. If these small water systems have to invest in additional expensive treatment processes, the cost burden may be more than many small communities can afford to pay.

In order to provide realistic information concerning these anticipated cost burdens, a field study of 10 small water systems in each of EPA Regions III, V, VI, VIII, IX, and X has been conducted. Costs were broken down according to acquisition, treatment, water delivery, and support services. Raw and finished water samples were taken at each utility and water quality problems identified. Where necessary, treatment technology designed to solve these problems was hypothesized, associated costs were calculated, and added to the existing baseline data. From this exercise, it was possible to realistically assess the costs of compliance which may be experienced by some small water systems. On the average for utilities studied, costs increased by 10% but for some individual systems costs increased by two or three times.

In parallel to the above-mentioned study, a field study of the cost effectiveness of package water treatment plants was completed. Package water treatment plants are prefabricated units constructed on site. This initial construction cost may be half that of conventional treatment.

The study revealed that properly operated package plants can treat water to meet the drinking water standards at reasonable cost.

A standardized cost accounting system that could be used by all utilities has been completed and operated for one year in a small utility. Work is currently under way to develop a financial reporting system that will utilize data from the cost accounting system to generate standardized fiscal reports.

Recently, an interim report from an extramural effort designed to determine the cost of various unit processes, singly and in combination, has been published. This report contains costs of conventional unit processes, and for such special unit processes as granular activated carbon.

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DISTRIBUTION SYSTEM WATER QUALITY

In the area of metal pipe corrosion, several projects are underway. A portable device for measuring the concentration of lead, zinc and cadium by anodic stripping voltametry has been developed under an interagency agreement and is now being field tested in the Seattle distribution system. This device should allow water utilities to easily assess the dissolution of the toxic metals lead and cadmium in their distribution systems.

In a grant with the University of Florida a number of systems in Florida are being evaluated in an effort to determine if a Modified Langelier Index or some other relationship might be more useful in predicting corrosion in metal pipes with the kind of water encountered in Florida. If these studies are successful the results should also aid utilities in other parts of the country as presently available corrosion indicators generally appear inadequate.

In-house studies on the corrosion of lead pipe are continuing and the influence of various corrosion control techniques such as the use of zinc orthophosphate and sodium bicarbonate addition with pH adjustment are being evaluated. An interesting side development of these studies has been the finding that it may be possible to analyze the films developed on the pipe in these studies or found on the pipe in natural systems by the use of Raman spectroscopy. The analysis of these films should enable us to more readily predict the effectiveness of attempts to control corrosion in any system.

In the area of organic contaminants, the possible migration of polynuclear aromatic hydrocarbons (PAHs) from asphalt or coal-tar lined pipes into the distributed water is being evaluated. Static tests have been conducted in the laboratory and a number of field installations utilizing asphalt (petroleum base) lined cast iron pipe have been studied. In the static tests, water is allowed to remain in contact with a short section of lined pipe for several days before being analyzed for PAHs. In the field studies, grab samples are collected at the end of an asphalt lined pipe. Thus far, in both cases, relatively low levels of PAHs have leached into the water. In the case of coal-tar lined pipes, however, total PAH concentrations as high as 4 μg per liter were found. Thus, further studies of both types are being conducted on coal-tar lined pipe to determine how long after installation these compounds continue to leach from the pipe and in what amounts.

Another study concerned with organic contamination has been an evaluation of the total organic chlorine determination developed in Germany by Kuhn, Fuchs and Sontheimer. In this determination, organohalides are adsorbed onto granulated activated carbon, the carbon undergoes pyrohydrolysis, and the resulting chloride is determined by microcoulometric titration. The method has been modified, simplified, and adapted also to the determination of disinfected water. The results of these latter studies have shown that much of the purgeable material remains unaccounted for when the original non-disinfected water methodology is used. A first production model of an instrument for measuring total carbon adsorbable halides is now being evaluated in-house.

With respect to particulate contamination, a grant with the City of Greenwood, South Carolina to treat its water with zinc orthophosphate in order to control corrosion of the asbestos cement (A/C) pipe in its system is nearing completion and preliminary data indicate that the treatment is helpful. An in-house study utilizing sections of A/C pipe inserted in a circulating system with water treated with zinc orthophosphate and adjusted to pH 8.3 also indicates that this treatment prevents softening of the pipe and loss of calcium from the pipe, whereas water untreated or treated with zinc orthophosphate but at pH 7.0 produced softening of the pipe and a significant increase in the calcium content of the water.

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MICROBIOLOGICAL TREATMENT BRANCH

The research strategy for the Microbiological Treatment Branch is addressing several issues in response to the proposed regulations for the control of organic chemical contaminants. These research areas include 1) the use of modified water treatment techniques including activated carbon and changing the point of disinfection, 2) the use of alternate disinfectants to chlorine such as chlorine dioxide, ozone, and chloramines, 3) application of the standard plate count as a means of evaluating changes in the sanitary quality of water, and 4) how all of these factors might be integrated to effect the overall quality of water. Research needs of EPA Water Supply Regional programs have also been identified and those areas of highest concern have been integrated into ongoing program directions or scheduled for early starts over the next two years.

The technical approach in the research strategy includes both intramural and extramural research in the laboratory, using pilot plant operations and field sites for full scale evaluations. This year's report summarizes research accomplishments in the area of distribution system quality, disinfection, point-of-use treatment attachments, and rapid methods development, during the period October 1977 to September 1978.

DISINFECTION

Research on the microbiological aspects of drinking water disinfection continues to have a high priority in the Microbiological Treatment Branch. The consideration of alternatives to chlorine for drinking water disinfection and the need for information on the relationship of turbidity to disinfection efficiency continue to be the major factors influencing the disinfection research program. Several extramural projects in this area funded in the last two years have been completed or are nearing completion.

The results of a study on the resistance of several enteroviruses to different chlorine species indicate that changes in pH within the range encountered in water treatment have important effects on the resistance of viruses to inactivation by chlorine. These effects are quite apart from the effects of pH on the disinfectant chemical species present. In addition, previous results indicating a pronounced effect on the disinfectant efficiency of chlorine by inorganic salts such as potassium chloride were confirmed. The results of this study show the difficulty in assessing the relative disinfection efficiency of chlorine species and other disinfectants and also some of the problems associated with attempts to choose a single virus to serve as a valid disinfection indicator under all circumstances.

Research on the effects of virus aggregation on disinfection resistance of enteroviruses and on the factors which influence virus aggregation and dispersion in water is in the final year of a three year project. Some of the more important results include: 1) the tendency of viruses to aggregate or disperse seems to be an individual characteristic of various enteroviruses but some common characteristics are evident. Aggregation does not appear to be related to viral isoelectric point. All viruses studied tend to aggregate at low pH (3 to 6) and to disperse at high pH (8 to 11). Low concentrations of metalic ions tend to enhance aggregation while higher concentrations enhance dispersion. Divalent and trivalent cations are more effective than monovalent cations and anions appear to have little influence. 2) While aggregation can cause deviation from first order inactivation kinetics, dispersed viruses do not always show first order inactivation kinetics. The reason for the deviation is unknown but does not appear to be genetically related. 3) The relationship between disinfectant concentrations and disinfectant rate is not linear. Although rates increase as disinfectant concentration increases, chlorine and bromine are more efficient at lower concentrations. Analysis of the initial phases of the inactivation patterns produced by HOCl and OCl^- suggest that the two disinfectants may inactivate viruses by different mechanisms.

As a result of the increasing frequency of waterborne outbreaks of giardiasis in recent years, a research program on the protozoan etiologic agent *Giardia lamblia* and on treatment technology needed to prevent such outbreaks was initiated in 1976. As a part of this effort, a symposium on *Waterborne Transmission of Giardiasis,* jointly sponsored by MERL and the Health Effects was held September 18-20, 1978 in Cincinnati. The purpose of the symposium was to assess the state of our knowledge of the organism, the disease, its epidemiology, detection methodology and treatment technology, and to determine the direction of future research in this area.

In attendance were approximately 200 people representing in approximately equal numbers governmental research and regulatory agencies, water utilities, and academic institutions. In addition to papers by MERL and HERL personnel and grantees, the program included presentations by National Institutes of Health, Communicable Disease Control, and U.S. State Department, Office of Medical Services personnel.

One of the highlights of the symposium was a report by a MERL grantee describing successful development of a culture method for determining *Giardia* cyst viability. This important breakthrough has made disinfection studies on this organism feasible and also is important with regard to detection methodology development. Disinfection research on the cysts of this microorganism is now in progress.

The results of three separate research projects relating to the effects of microbial association with particulate matter on the disinfection efficiency of chlorine, chlorine dioxide, and ozone were presented at the annual American Water Works Association meeting in Atlantic City in June 1978. The results of each of these studies bear out initial findings indicating that the degree of protection conferred depends to a great extent on the type of particulates associated with the microorganisms rather than the amount of particulate matter present as measured by turbidity. Final reports on these projects will be available in FY-79.

The Microbiological Treatment Branch staff participated in the preparation of a Report to Congress entitled, *Human Viruses in the Aquatic Environment: A Status Report with Emphasis on the EPA Research Program.* Preparation of this report was mandated by the Safe Drinking Water Act. It will serve as a guide to Congress and the Agency in determining the future course of virus research related to drinking water.

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DISTRIBUTION SYSTEM STUDIES

After treatment, potable waters are subject to continuing deterioration of microbiological quality. The extent of this microbial degradation is dependent on source water quality, type of treatment, residual disinfectant, distribution/storage system design, climate and other physical and chemical factors. To assess the impact of these factors on finished water quality, the Microbiological Treatment Branch has several extramural projects and in-house tasks related to field and laboratory studies of microbiologically mediated deterioration in distribution systems.

Ongoing field studies are evaluating the effects of turbidity levels greater than one unit on bacterial survival and regrowth in distribution systems in areas of the Northeast (Salem-Beverly, Massachusetts and Nasson College, Maine), MidAtlantic (University of Delaware and Johns-Hopkins University), Midwest (University of Missouri) and West Coast (University of California). In addition to the turbidity aspect of these studies, they each include related areas of study peculiar to the given system. Salem-Beverly, for instance, has been studying chlorine resistant, encapsulated bacteria imbedded in sediment deposits in their distribution system as well as identifying the other bacterial groups present and relating population changes to treatment modifications. A grant with ORSANCO (Ohio River Valley Water Sanitation Commission) is also studying effects of treatment modifications on the bacterial quality of water supplies. Johns-Hopkins University has been studying the problems related to cross-conections and is now beginning a study of pathogen survival in a turbid, finished water system. A related in-house task is evaluating the effect of handling and storage on bacteriological changes in potable water samples prior to analysis. Information being developed in this project has a direct bearing on all the distribution studies as well as an impact on utility compliance with the Drinking Water Standards, since some sample storage is inevitable in any distribution system sampling program.

Previous results have demonstrated that the type of turbidity is as important as the amount, with regard to disinfection and bacterial survival. Studies at Oregon State University, University of California and Nasson College (Maine) will attempt to identify the physical and chemical parameters contributing to the various types ot turbidity, and how these factors relate to bacterial growth and treatment effectiveness. The California study includes two systems; one providing full treatment and the other using only disinfection. A manual on treatment modification an distribution system maintenance will be the final output of the field and laboratory studies being conducted by the University of Missouri on corrosion related to microbial growth and sediment accumulations in water mains. An in-house task is also studying the interactions between microbial activities and water main deposits. Tubercle samples from eight different systems have been chemically analyzed and evaluated for bacterial growth enchancement. Electron micrographs of some of these sediments have demonstrated bacterial survival and protection in the interstices. Two other in-house tasks are attempting to identify the microflora of a finished water distribution system. The occurrence of pigmented organisms, their disinfection resistance, and population changes during treatment are being emphasized.

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POINT-OF-USE TREATMENT DEVICES

Laboratory evaluations of point-of-use carbon filters were initiated early in fiscal year 1978 in response to considerable consumer interest and requests for technical assistance from both the Office of Drinking Water and the Office of Pesticide Programs. Five different carbon filters have been tested using Cincinnati tap water an a timed sequential flow through the testing apparatus. Several filters have also been installed on fountains in the EPA-Cincinnati research facility. Weekly samples have been evaluated for Standard Plate Count, trihalomethan concentrations, total organic carbon levels, and free chlorine residual. Generally, filter efficacy is dependent on flow. Rapid, high volume flow prevents bacterial build-up on the carbon, but also precludes effective removal of the chemical contaminants. Low flow results in more effective removal, but allows significant bacterial growth in the filter. Several more filters will be evaluated. Also, assistance has been provided to the Office of Drinking Water on initiating a contract to evaluate a large number and variety of these home use devices.

METHODS DEVELOPMENT

Recent developments in the field of water treatment have indicated that some organic compounds in finished water can react with chlorine to form carcinogenic compounds. As a result, there has been a trend toward modifying potable water treatment practices to reduce the potential for formation of such carcinogenic compounds. However, changes in treatment technology may alter the protective barrier provided by maintenance of a free chlorine residual in the distribution system. If this protective barrier is thus reduced, the need for rapid bacteriological monitoring or detection systems and for emergency treatment technology will be mandatory.

Research is in progress to examine the use of the firefly luciferase adenosine triphosphate (ATP) assay for monitoring the concentration of bacteria in distribution system water. Successful development of this technique would permit bacteria, to be concentrated from a sample volume as large as 60 liters, followed by extraction and measurement of bacterial ATP, all in a total time of one hour or less. The key to the success of the ATP assay as a semi-automated or an automated test depends on development of a reliable concentration method that can be coupled to an existing in-line ATP extraction procedure. This assay could provide an excellent tool for quality control of the treatment process and for following the bacteriological quality of water at various points in the distribution system.

The need to examine samples of treated drinking water larger than two ml when determining the total bacterial count requires the use of a membrane filter standard plate count procedure. This laboratory has now developed medium suitable for membrane filter work and forthcoming publication of the method will allow other interested users to implement it and evaluate its usefulness.

Efforts have been continued in the development of a rapid quantitative ^{14}C-radiometric procedure for detection of fecal coliform bacteria in water. Primary emphasis has been given to establishing the precision and reproducibility of the ^{14}C-mannitol method using water samples from various surface sources. Other experimental work compared $^{14}CO_2$ release from ^{14}C-mannitol (uniformly labeled) and with ^{14}C-lactose (uniformly labeled). The use of the ^{14}C-mannitol method proved better in the short time frame (maximum 6 hours) established for the procedure. All work to date indicates that a direct relationship exists between $^{14}CO_2$ release and fecal coliform concentration, but the magnitude of $^{14}CO_2$ release is variable due to stress, injury and/or other undetermined factors.

While there has always been concern over the numbers of bacteria present in potable water, little interest has been shown in reference to what specific types of bacteria were present except for coliforms or enteric pathogens. Recently, interest in knowing what kinds of bacteria may establish residence in distribution systems has stimulated new research. Non-enteric bacteria in sufficiently high numbers may be important in terms of interference with detecting the presence of coliform bacteria in distribution water. A study has been understaken to isolate and identify the non-coliform bacteria from a portion of Cincinnati's distribution system. Identification of these organisms is difficult and has resulted in development of a new medium for propogation of the organisms in order to carry them in laboratory subculture. Special methods for biochemical characterization have been implemented in conjunction with the use of commercially available bacterial identification systems. Special training offered by the Center for Disease Control, Atlanta, Georgia, was also necessary.

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INTERNATIONAL ACTIVITIES

FOREIGN VISITORS

During FY '77 and '78 the Municipal Environmental Research Laboratory (MERL)-Cincinnati received 52 foreign visitors representing national and local governments, industry, academic and other institutions from 15 countries. The countries represented by these visitors and the number from each during this period were: Australia 6; Sweden 6; France 5; Japan 5; Poland 5; Bulgaria 4; England 4; Italy 3; Portugal 3; Switzerland 3; Iran 2; Finland 2; Tunisia 2; and one each from Egypt and Germany.

These visitors were interested in all phases of the work in MERL. Quite often other laboratories within the Environmental Research Center were also visited.

COMMITTEE ON THE CHALLENGES TO MODERN SOCIETY (CCMS)

This NATO-sponsored committee attempts to bring together several countries in various peaceful endeavors. The Municipal Environmental Research Laboratory has been involved in projects on wastewater treatment and drinking water supply research. Dr. Robert L. Bunch, WRD, is a member of the Advanced Wastewater Treatment Group and U.S. Representative.

ORD's active participation in CCMS began in January 1973 and is to continue until December 1978. Yearly workshops are held to provide various technical discussions of wastewater technology and serve to acquaint all participants with the research going on in member countries.

Two projects were conducted, one on advanced treatment of wastewater by physical-chemical processes and one on the use of pure oxygen in activated sludge t:pilot plant at Wuppertal.

The last meeting of the delegates was in London on June 21, 1978. The draft final report was reviewed and all comments resolved. The report will be published by December 1978. This will complete the task of the Advanced Wastewater Treatment Committee.

PILOT STUDY ON DRINKING WATER STUDIES

Gordon G. Robeck is the MERL representative for the CCMS drinking water project which held its first meeting in April 1977 in Brussels, Belgium. Follow-up meetings took place in October 1977 in London,

FINLAND 2
SWEDEN 6
ENGLAND 4
GERMANY 1
FRANCE 5
SWITZERLAND 3
POLAND 5
PORTUGAL 3
ITALY 3
IRAN 2
JAPAN 5
TUNISIA 2
EGYPT 1
BULGARIA 4
AUSTRALIA 6

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England in April 1978 in Bonn, West Germany, and in September 1978 in Karlsruhe, West Germany.

The objectives of the pilot study are to achieve a better understanding of: (1) the drinking water problems shared by industrialized countries, (2) solutions to these problems now available, and (3) potential problems for which solutions are currently not available (except, perhaps, a prohibitive costs).

Topics to be included are analytical chemistry, treatment technology, sampling, water contaminants and their health effects, water reuse and ground water protection. Results will be in the form of reports and international conferences and direct meetings with responsible authorities. The study is expected to be completed in the Spring of 1979 with the meeting in Reston, Virginia on the subject Adsorption Techniques in Drinking Water Treatment.

PUBLIC LAW (PL) 480 PROJECTS

Under PL 480, U.S. counterparts in foreign countries are being used to finance projects designed to advance scientific and technical research in the particular country as well as in the U.S. From MERL project officers supervise investigations relating to the identification and solution of environmental problems.

TITLE: Water Reclamation and Useful Utilization of Sewage Solid Waste
LOCATION: University of Karachi, Karachi, Pakistan
GRANT PERIOD: October 1, 1976 to December 21, 1980
PRINCIPAL INVESTIGATOR: Dr. M. Zain-ul-Abedin
PROJECT OFFICER: Robert L. Bunch, MERL-Cincinnati, WRD, TPDB
(Phone: 684-7655)

TITLE: Investigations of Biodegradability and Toxicity of Organic Compounds
LOCATION: Institute of Meteorology and Water Economy, Warsaw, Poland
GRANT PERIOD: March 1, 1975 to February 28, 1978, Extended to February 28, 1979
PRINCIPAL INVESTIGATOR: Dr. Eng. Jan Dojlido
PROJECT OFFICER: Robert L. Bunch, MERL-Cincinnati, WRD, TPDB
(Phone: 684-7655)

6th U.S./JAPAN CONFERENCE ON SEWAGE TREATMENT TECHNOLOGY

Many of the problems of waste treatment are common among the highly-developed countries of the world. Since 1971, the United States and Japan have shared wastewater treatment technology through a cooperative agreement. The agreement has proven to be mutually beneficial, and has promoted technology transfer to support both countries' extensive research programs. The cooperative agreement has resulted in a series of conferences held at approximate 18 month intervals. During 1978 the 6th Conference was held from October 30 through November 3.

On October 30 and November 1, members of the U.S. and Japanese teams convened at the Environmental Research Center in Cincinnati to hear technical presentations. Representatives of the Japanese team presented papers on nitrogen control and removal, sewage sludge de-watering and incineration, use of pure oxygen, color removal of dyeing wastewater and automatic water quality monitoring equipment. The United States team presented papers on sludge treatment, instrumentation and automation, and the programs of the Ohio River Valley Water Sanitation Commission (ORSANCO).

On November 2 and 3, the conference reconvened in Washington, D.C. at the EPA Waterside Mall. The theme shifted from scientific to institutional, fiscal and organizational problems of mutual interest. The Japanese team presented papers on institutional structures, sewage works financing, sewer use charge systems, automatic control systems and activities of the Japan Sewage Works Agency. The U.S. team presented papers on recent legislation amendments, the construction grants program, program planning and implementation in Washington, D.C. and Virginia and pretreatment standards.

The Chairman of the 6th Conference is Mr. F.M. Middleton, Senior Science Advisor, MERL. He is also Head of the Cincinnati U.S. Delegation. Dr. T. Kubo is Co-Chairman of the Conference and Team Leader, Vice-President, Japan Sewage Works Agency.

FOREIGN TRAVEL AND MEETINGS ATTENDED

Dr. Robert L. Bunch

In October 1977 trips were made to Warsaw and Katowice, Poland, to monitor PL 480 projects and to attend the World Conference of the Soap and Detergent Association at Montreux, Switzerland.

Monitored research project PL 480 at University of Karachi, Karachi, Pakistan on June 4-10, 1978.

June 11-17, 1978, attended the IAWPR 9th International Conference on Water Pollution at Stockholm, Sweden.

Attended the regularly scheduled NATO/CCMS committee meeting on Advanced Wastewater Treatment in London, June 21, 1978. The draft report of this committee was reviewed and cleared by the delegates. The report finishes the work of this committee.

As a team member two papers, "Wastewater and Sludge Research Program", and "Measuring the Degree of Sludge Stability," were presented October 31, 1978, at the 6th US/Japan Conference on Sewage Treatment Technology in Cincinnati, Ohio.

On December 5 and 6, 1978, presented two invited papers, "Pilot Plant Development of Ozone Disinfection" and "The Future Course of Wastewater and Sludge Disinfection," at the 2nd International Congress of the Environment, Paris, France.

Francis M. Middleton

In April of 1978 F.M. Middleton visited Tunisia, North Africa at the request of the U.S. State Department/Agency for International Development to advise the Tunisian Government regarding a new water pollution control activity and laboratory.

Gordon G. Robeck

In October 1977 to London, England for the NATO/CCMS Pilot Study on Drinking Water Supply Problems and in October 1978 to Kyoto, Japan to participate in the International Water Supply Congress Association by representing the USA on virus control, granular activated carbon treatment, and micropollutant control by oxidants.

Dr. James M. Symons

In April 1978 to Bonn, West Germany for the NATO/CCMS Pilot Study on Drinking Water Supply Problems and visits to water treatment plants in Dusseldorf, Wuppertal, Siegburg, West Germany.

Jesse M. Cohen

At the invitation of Dr. P.R. Philip of the Ministere de 1'Environnement et du Cadre de Vie, Paris, France, two papers were presented to the 2nd International Congress of the Environment on December 5 and 6, 1978. The papers were entitled "Observations on Physical-Chemical Treatment in the USA" and "Pilot Plant Investigations on Physical-Chemical Treatment."

Alan A. Stevens

In September 1978 to Karlsruhe, West Germany for the NATO/CCMS Pilot Study on Drinking Water Supply Problems. He presented a paper there at the Oxidation Techniques in Drinking Water Treatment Session on Unwanted Byproducts of Chlorination. On that same visit, Mr. Stevens also visited water treatment plants in Zurich, Switzerland; Dusseldorf, Wupertal, and Mulheim, West Germany and Rotterdam, Holland and research institutes in Karlsruhe and Essen, West Germany; Dubendorf-Zurich, Switzerland; and Hague, Jutphass and Rijswijk, the Netherlands; and Medmenham, England.